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# Sediment flux & fate for a large-scale diversion: the 2011 Mississippi River Flood, the Bonnet Carré Spillway, and the implications for coastal restoration in south Louisiana

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SEDIMENT FLUX & FATE FOR A LARGE-SCALE DIVERSION: THE 2011 MISSISSIPPI  
RIVER FLOOD, THE BONNET CARRÉ SPILLWAY, AND THE IMPLICATIONS FOR  
COASTAL RESTORATION IN SOUTH LOUISIANA

A Thesis  
Submitted to the Graduate Faculty of the  
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Master of Science

In

The Department of Geology and Geophysics

by  
Jeffrey B. Fabre  
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## **PREFACE**

This thesis is in “journal” format. The primary article that has resulted from this research is presented in Chapter 2, which is in preparation for submission to *Geophysical Research Letters*, under the title of “Fine sediment flux and dispersal in a large river diversion: the 2011 Flood of the Mississippi River, the Bonnet Carré Spillway, and Lake Pontchartrain, Louisiana”. An introduction to the topic and study area is provided in Chapter 1. Chapter 3 presents data and analysis that are relevant to the study but not essential to the manuscript presented in Chapter 2. A synthesis, summary, and conclusions are presented in Chapter 4.

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## ABSTRACT

Dams and hardened levees built by European settlers in the last two centuries have degraded or stopped the cyclic sedimentation patterns that built the Mississippi River Delta Plain over the past 7,000-8,000 years. Man-made diversions of sediment-laden river water along the lower Mississippi, operated during high water periods, are being considered as a primary mechanism for combating the land loss induced by rising sea-level and these modern controls. To date, no study has documented the sediment-delivery potential of a large man-made river diversion during a single high water event. In the spring of 2011, historic flooding on the Mississippi River delivered record river and sediment discharge to the Delta, and the U.S. Army Corps of Engineers opened floodways, including the Bonnet Carré Spillway, to keep the Mississippi River at acceptable stage elevations near New Orleans. The Bonnet Carré Spillway connects the Mississippi River upstream from New Orleans to Lake Pontchartrain. We studied river-sediment flux and fate from the spillway into Lake Pontchartrain as an analog for future river-sediment diversions under consideration at present. The spillway was open from May 9 to June 20, 2011, reaching peak flows  $> 8,000 \text{ m}^3/\text{s}$ , at the upper end of diversion flow considered for land-building, making the spillway for a short time one of highest discharge waterways in North America. To develop a sediment budget, sediment cores were collected across the  $\sim 1500 \text{ km}^2$  lake before, during, and after the operation of the spillway. Cores were analyzed for grain size and the cosmogenic radionuclide  $^7\text{Be}$ . Results show that the plume rapidly dispersed across most of the lake, and deposited a clay to coarse-silt-sized sediment layer with a total mass of  $\sim 1.1\text{-}3.8 \text{ MT}$ . This flux is comparable to the sediment flux measured in the few other modern diversions that are building land, and suggests that such diversions, if operated on a regular basis

during high flows when both sediment concentration and discharge are highest, may provide an important tool for conserving and building land in the shrinking Mississippi Delta.

# **1. GEOLOGIC HISTORY AND SETTING**

## **1.1 The Mississippi River Delta Plain**

The dynamic and cyclic nature of the Mississippi River's delta plain is well documented and has been studied for more than a half century (Russell, 1936, Fisk, 1944, Fisk, 1952, Coleman & Gagliano, 1964, Coleman, 1988, Roberts, 1997, Roberts, 1998, Roberts et al., 2003). Over the last 7,000-8,000 years, the river has produced six individual and overlapping delta lobes, each having an active lifetime of 1,000-2,000 years (Fig. 1, Roberts, 1997). Each lobe has built due to river sedimentation, and then entered a declining phase due to decreased competency and abandonment of the active lobe's channel, which has then led to avulsion and channel relocation, to create a new lobe along a more desirable path. This process is often referred to as the "delta cycle" and is described in a seminal paper by Dr. Harry Roberts (1997) as an interrelated system of constructive, progradational, regressive features, and destructive, transgressive ones. It is important to note that the delta plain has always undergone erosion and deposition simultaneously throughout its existence, but large sedimentation rates, lobe changes, and stable sea-levels have allowed for the creation of a ~24,000 km<sup>2</sup> subaerial delta plain entirely within the Holocene (Coleman, 1988, Roberts, 1997, Blum & Roberts, 2009).

The delta lobe that has persisted for the past ~1,000 years has been called the Balize lobe, now a shelf-edge delta often referred to as the "Birdfoot Delta" due to its morphology (Fig. 1, Coleman, 1988). Remnants of numerous 150-300 km<sup>2</sup> sub-deltas, produced when river water breaks through the natural levees and builds up land to form crevasse splays, are seen throughout the lower extent of the Balize lobe (Fig. 2, Coleman & Gagliano 1964). These smaller scale features are analogous to their larger scale counter-parts and undergo their own 150-200 year cycles (Roberts, 1997).

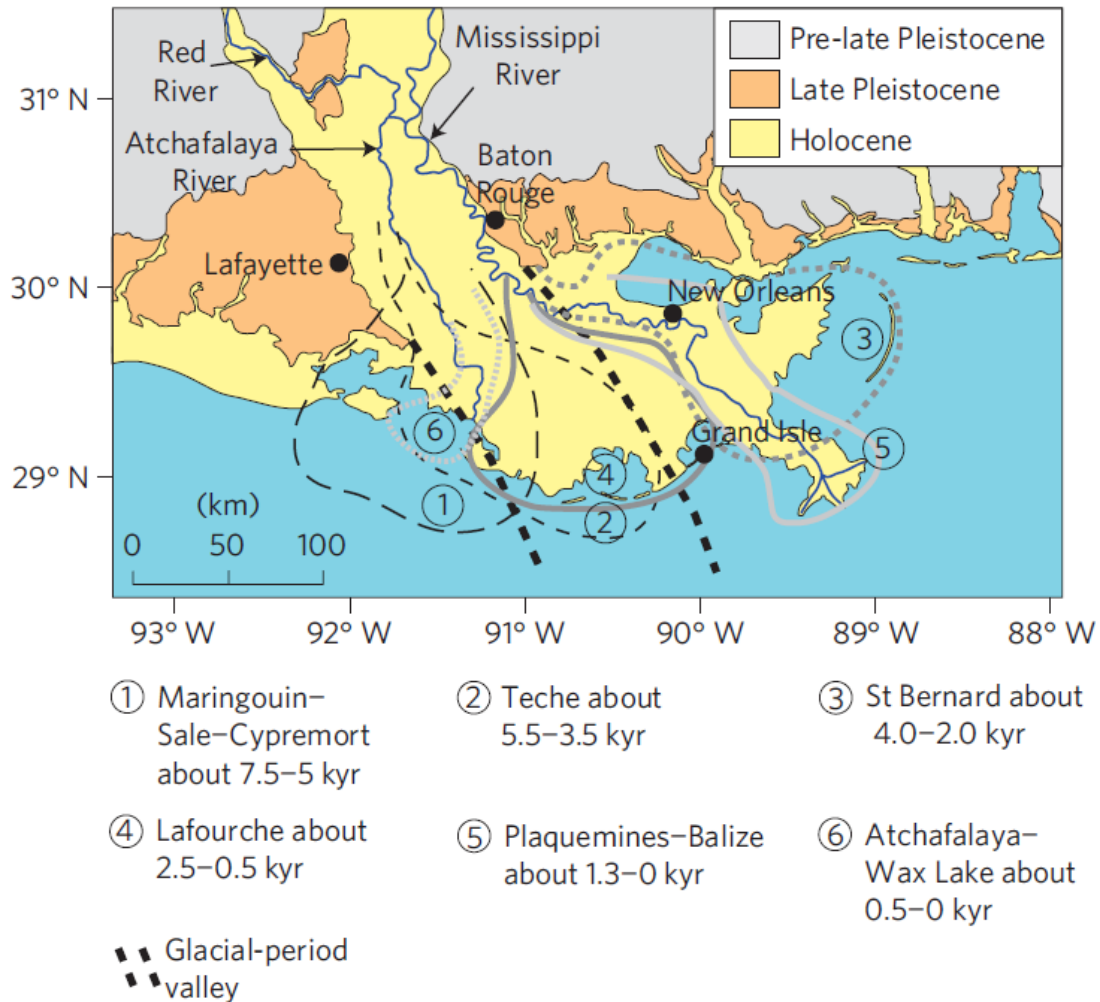


Figure 1. Mississippi River Delta Plain Geology (Blum & Roberts, 2009)

The Balize lobe is at the end of the constructive phase of the delta cycle, most emphatically demonstrated by the tendency for capture of the Mississippi River by the Atchafalaya River, one of the Mississippi's main distributaries, within the last ~400 years. Over the last 200 years, this natural progression has been interrupted by activities of European and then American settlers, with associated dams, levees, and other engineering constraints on the Mississippi River system that have altered flow and sediment delivery patterns (McPhee, 1989, Roberts, 1997).

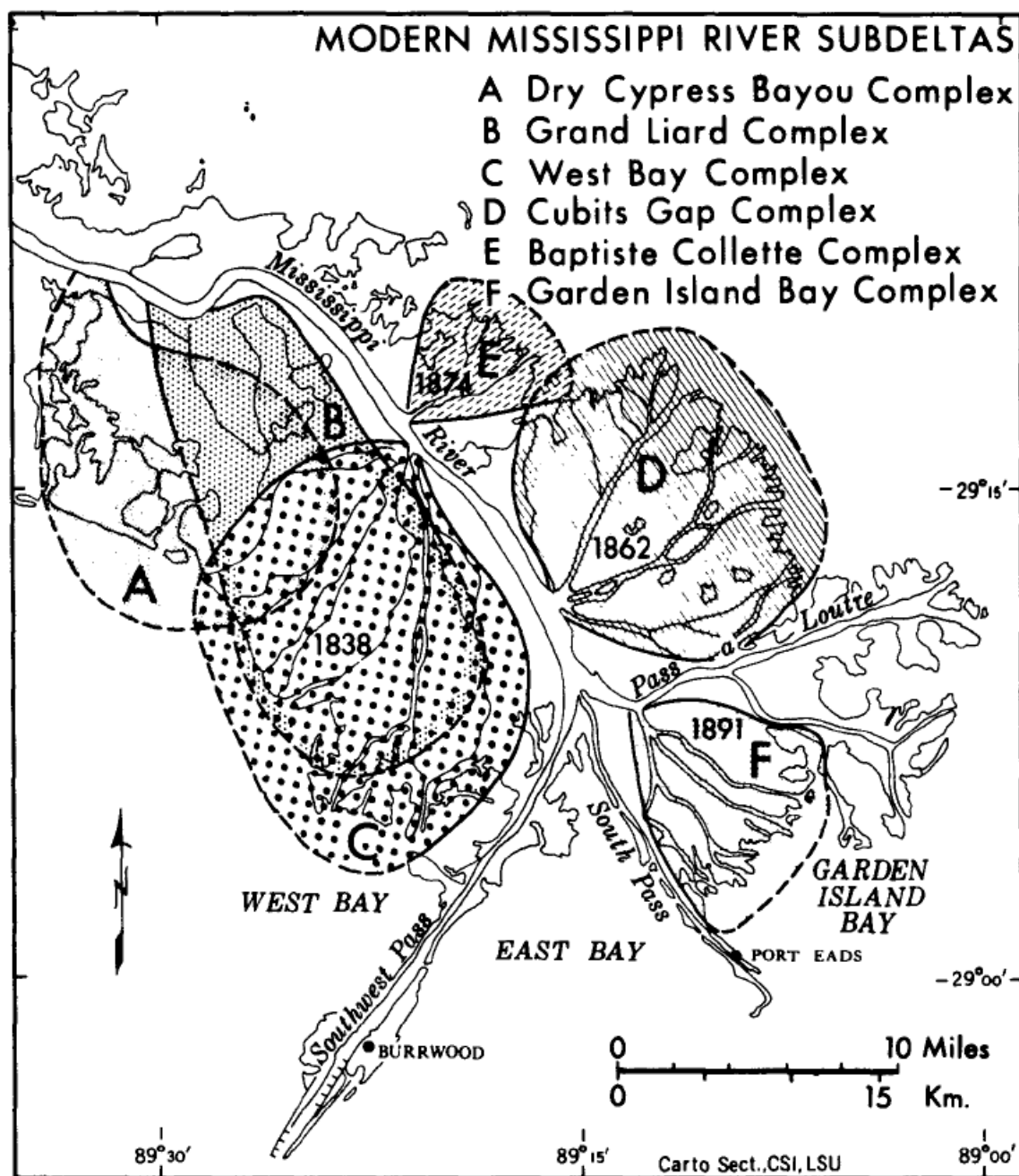


Figure 2. Sub-deltas within the Balize "Birdfoot" Delta (Coleman, 1988)

## 1.2 Human Influence in the Modern

Although construction of levees and river control structures along the Mississippi began with first European settlement in the early 18<sup>th</sup> century, the most extensive phase of river-control engineering began in the mid 19<sup>th</sup> century, and was severely tested during this time by major episodic floods (McPhee, 1989; Barry, 1997). Due to the military implications of South Louisiana in the 19<sup>th</sup> century, the US Army Corps of Engineers (US-ACE) was put in charge of controlling the Mississippi in order to protect the existing big cities and industries that had developed on it. In 1927, one of the biggest floods in American history struck most of the lower alluvial plain of the Mississippi and devastated much of South Louisiana. As a result, the US-ACE began to put in place an intricate system of levees, locks, dams, and control structures designed to preserve and maintain the flow conditions of both the Mississippi River and its newly desired path, the Atchafalaya. In 1973, another large flood nearly undermined the Old River Control Structure (built to control flow among the Mississippi, Red, and Atchafalaya rivers), and brought the control structure very close to catastrophic failure, which could have led to full capture by the Atchafalaya (McPhee, 1989).

Previous to this flood, increased flow and sediment concentrations in the Atchafalaya River began to fill inland bodies of water and bays, in particular, the Atchafalaya Basin and the Atchafalaya Bay, with sediment (Roberts 1997 and 1998). Even though failure of the control structure was avoided in 1973, that flood enhanced sedimentation in the Atchafalaya by scouring the river to such an extent that coarser sediment could now bypass these inland areas and began to build sandy subaerial delta lobes in Atchafalaya Bay (Roberts, 1997 and 1998). By 1997, the Atchafalaya River and one of its main spillways, the Wax Lake Outlet, had created ~150 km<sup>2</sup> of new land in the form of two bay-head deltas (Fig. 3, Roberts 1998). This process is characteristic

of the early constructional phase of the delta cycle and signifies that the Atchafalaya-Wax Lake system is the latest lobe within the Mississippi River Delta Plain (Roberts et al., 2003).

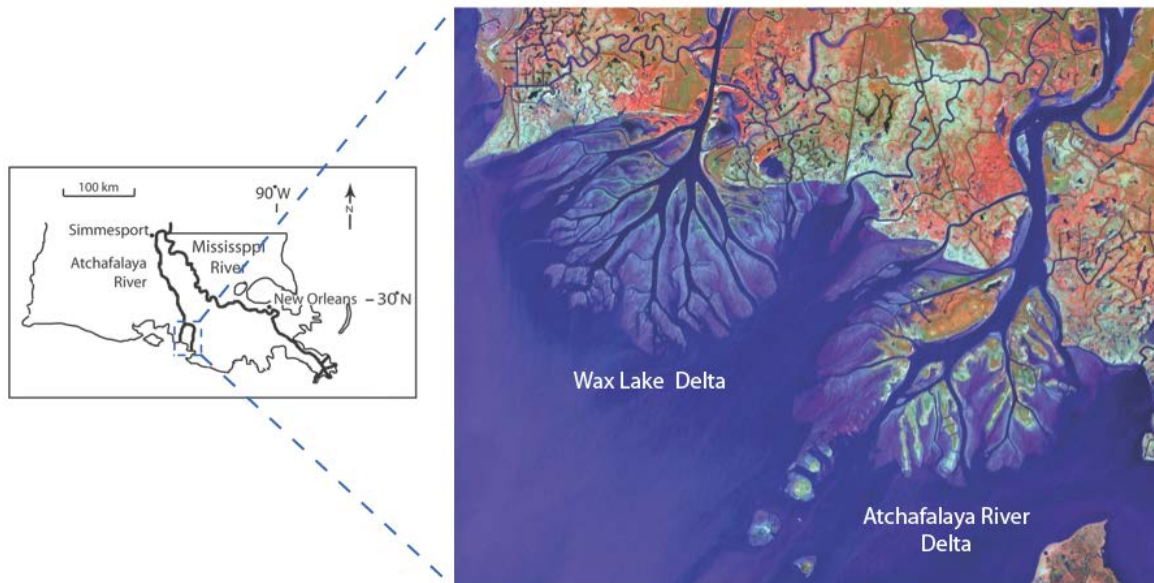


Figure 3. Wax Lake and Atchafalaya River Deltas (Landsat 5 Image, LSU Northern Gulf Institute, Image Provided by USGS)

The US-ACE continues to strengthen Mississippi levees and controls in response to flood events, and a large majority of these structures prevent the Mississippi River from periodically flooding the delta plain, which has been a key sediment delivery process for the delta over its geologic history (Coleman, 1988). Floods will typically overwhelm natural levees to form crevasse splays like the ones displayed in Figure 2, but engineered increases in levee height and rigidity have prevented this process from naturally happening at the rate it did before human involvement (Day et al., 2007). However, no matter the extent of controls, floods continue to occur, and in the spring of 2011, one on a scale not seen since The Great Flood of 1927 would provide an opportunity to study the effects of “reconnecting the river to the delta”, a method of restoration currently being discussed as a way of somewhat reestablishing the processes that naturally built the Mississippi River Delta Plain in the past (Andrus and Bentley, 2007, Snedden et al., 2007, Blum & Roberts, 2009, Day et al., 2009, Kim et al., 2009, Paola et al., 2011).

## **2. SEDIMENT FLUX & FATE FOR A LARGE SCALE DIVERSION: THE 2011 MISSISSIPPI RIVER FLOOD, THE BONNET CARRÉ SPILLWAY, AND THE IMPLICATIONS FOR COASTAL RESTORATION IN SOUTH LOUISIANA**

### **2.1 Introduction**

Recent studies indicate that up to  $\sim 13,000 \text{ km}^2$  of land may be lost in the lower Mississippi River Delta by 2100, due to decreased sediment supply, sea level rise, and man-made control structures (Blum & Roberts, 2009). Historically, the delta plain has been built through a series of six successive delta lobes, each representing the progradational phase of the Mississippi's terminus during their respective times, and, as a whole, creating what we now call Southeast Louisiana (Coleman, 1964, Roberts, 1997). In the last three centuries, European influence has interfered with this dynamic and ever-changing "delta cycle" through extensive leveeing and the construction of numerous dams along the entire Mississippi River, which have decreased sediment supplies to the lower river by half, restricted delta growth, and put the delta plain in an overall transgressive phase that may prove irreversible well into the foreseeable future (Blum & Roberts, 2009).

Even so, modern diversions of the Mississippi prove that land can be built under current conditions. In the 19<sup>th</sup> century, a manmade cut in the Mississippi River at Cubit's Gap (between Venice and Head of Passes), created a crevasse splay that produced  $>200 \text{ km}^2$  of new land in  $\sim 75$  years (Roberts, 1998, Paola et al., 2011). The Wax Lake Outlet, a flood diversion on the Atchafalaya River put in place during the early 1940's to ease flood pressure on Morgan City, has built  $\sim 100 \text{ km}^2$  of land over the past 30 years through the formation of the Wax Lake Delta (WLD) (Roberts, 1997). Using these examples as an analog, man-made diversions of sediment-laden river water are being discussed as a primary mechanism for coastal restoration (Miller, 2004; Andrus and Bentley, 2007; Snedden et al., 2007; Barras et al., 2009, Blum and Roberts,



2009, Day et al., 2009, Kim et al., 2009, Paola et al., 2011, CPRA, 2012). Mathematical projections by Kim et al. (2009) to build new land by cutting the levees below New Orleans suggest potential land growth on the same scale as Wax Lake and Cubit's Gap, but conducting field-based research on large diversions is necessary for a full understanding of how these dynamic systems react in the real world and to validate and explore implications of model simulations.

In the Spring of 2011, record flood levels in the lower Mississippi River prompted the opening of the Bonne Carré Spillway for 42 days (9 May to 20 June) to take pressure off of New Orleans by diverting water 19km upriver of the city into Lake Pontchartrain (Fig. 4). At  $>8,000 \text{ m}^3/\text{s}$  of sediment-laden flow, the spillway was the second largest fluvial conduit in the United States for approximately one month, in terms of discharge, and provided an ideal scenario for conducting a first-time sediment-dispersal study of a man-made diversion at a scale that, up until now, has only been modeled (US-ACE, 2011, Kim et al., 2009, Allison & Meselhe, 2010). The objectives of this study are to quantify the flux, dispersal, and deposition of muddy sediment entering Lake Pontchartrain from the Mississippi River via the Bonnet Carré Spillway during its operation in the Spring of 2011. We can then use these measurements to focus on its relative land building potential, and provide a large scale, field-based analog for future proposed diversions of similar flow magnitude.

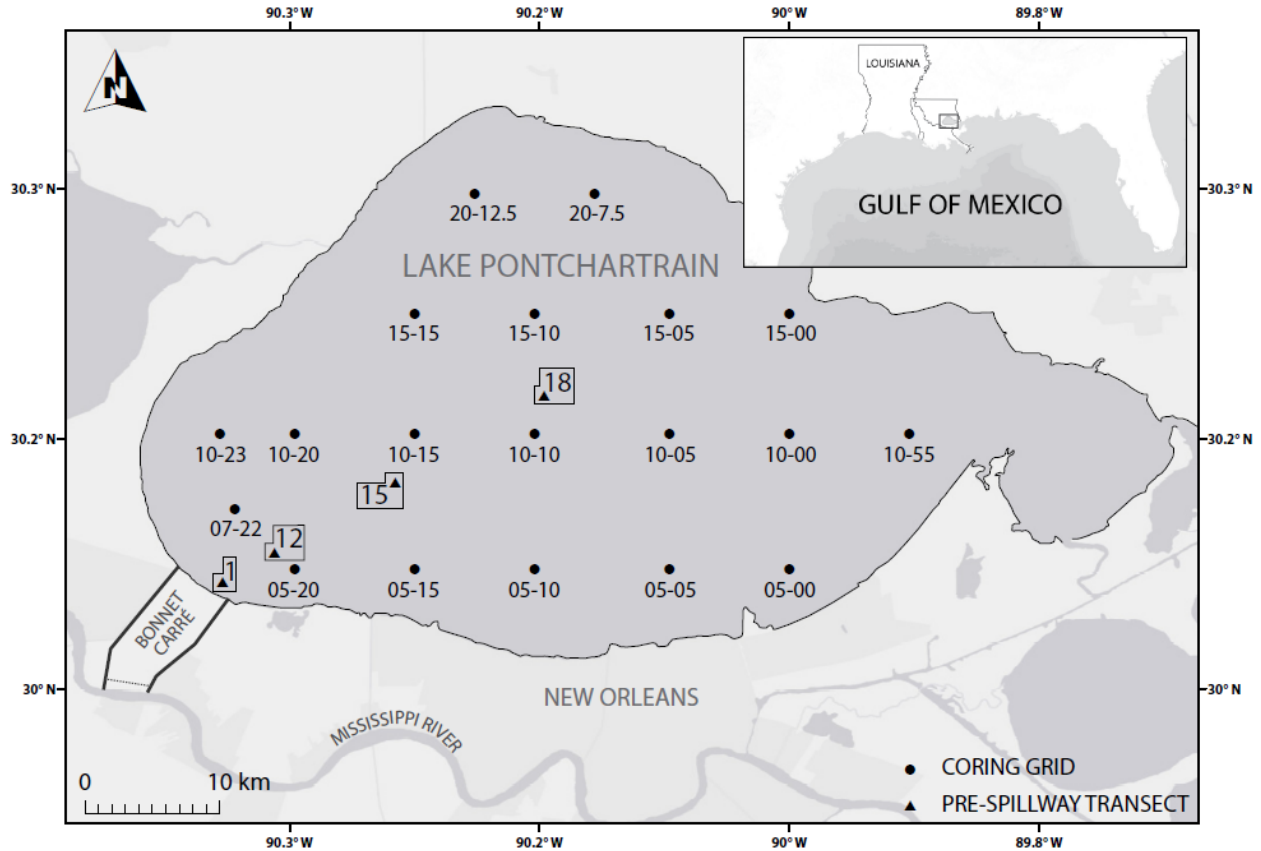


Figure 4. Field Setting and Survey Grid. Includes our coring grid for the 12-13 May, 2011 and 7-8 July, 2011 surveys and the pre-spillway transect collected by Dr. John White on 8 May, 2011.

## 2.2 Methods

Three lakewide push-core sampling surveys were conducted in Lake Pontchartrain during and after the operation of the spillway (12-13 May, 7-8 July, and 25-26 August 2011), and a smaller number of cores were collected along a transect on 8 May, 2011, the day before spillway opening commenced (9 May, 2011) (Fig. 4). Lakewide sample locations were distributed across a uniformly spaced grid encompassing the entire lake, except for additional stations near the spillway outflow, and the linear transect of cores collected 8 May, 2011 (Fig. 4). Two 7.5cm-diameter, 70cm long PVC push cores were collected for each station for the July and August surveys, and one core per station was collected for all May sampling, due to logistical constraints. Measurements for May and July only are discussed in this chapter. The May survey

could not be started until three days after spillway opening, due to the short notice provided by the US-ACE for spillway operation and logistics of vessel scheduling, and equipment failure prevented core collection at five of 19 stations (Table 1). The four cores collected on May 8<sup>th</sup> near the mouth of the spillway by Dr. John White of LSU Oceanography and Coastal Sciences provide sediment data prior to spillway opening. One core from each station for each survey was extruded and sampled every 2cm.

Sub-samples from the top 2cm of the extruded cores underwent grain size analysis on a Horiba LA-950 Laser-Diffraction Particle Analyzer, following dispersal in 0.05% sodium phosphate solution, and immersion in an ultrasonic bath. Additional subsamples for each core interval were prepared for gamma-spectrometry radioisotope analysis, and were dried, powdered, weighed and sealed air-tight in plastic petri dishes. Samples for radioisotopic analysis were analyzed via gamma spectrometry on a Canberra GL 3825 planar low-energy germanium detector, with 12-24 h counting times. This study focuses on the short-lived radioisotope Beryllium-7 (<sup>7</sup>Be), which has a 477.6 KeV gamma photon signature, half-life of 53.3 days, and is highly particle reactive (Baskaran et al., 1993, Corbett et al., 2007). <sup>7</sup>Be is produced by cosmic ray spallation, a process in which cosmic rays bombard nitrogen and oxygen atoms in the Earth's atmosphere and produce Beryllium radioisotopes that can then be captured and deposited by precipitation (Baskaran et al., 1993).

Cosmogenic <sup>7</sup>Be has been shown to be a useful tracer of sedimentary processes over seasonal timescales due to its availability, short half-life, and high particle reactivity (Olsen et al., 1986, Baskaran et al., 1997, Sommerfield et al., 1999, Rotondo and Bentley, 2003, Andrus & Bentley, 2007, Corbett et al., 2007). Runoff in large river basins can concentrate and increase <sup>7</sup>Be activities in river-channel sediments, compared to activities produced by vertical deposition

alone (Corbett et al., 2007, Baskaran et al., 1997), especially after storm events such as those of April of 2011 that caused flooding in the Mississippi River throughout the month of May (NOAA, 2012).

Detection efficiency for  $^7\text{Be}$  (which is not generally available as a standard reference material) was determined by interpolation for efficiency at the 477 KeV energy, between adjacent peak energies of known efficiency (measured in standard reference materials from the National Institute of Science and Technology, and the International Atomic Energy Agency). Activities were decay-corrected to date of sample collection, and are reported in decays per minute per gram (dpm/g). Sediment-bound inventories of  $^7\text{Be}$  are calculated using Equation 1 (after Corbett et al., 2007), where  $^7\text{Be}_I$  is the total inventory in each core (dpm/cm<sup>2</sup>),  $X_i$  is the thickness of the sample extruded from the core (cm),  $\phi$  is the sample's porosity (measured by water loss at 90°C),  $\rho_s$  is the density of the sediment (assumed to be 2.65 g/cm<sup>3</sup>), and  $^7\text{Be}_A$  is the massic activity (dpm/g).

$$^7\text{Be}_I = \sum X_i(1-\phi)\rho_s(^7\text{Be}_A) \quad (1)$$

MODIS Satellite images were compiled by the Louisiana Earth Scan Laboratory (ESL) for each sampling period, to qualitatively track suspended sediment distributions. Images were georeferenced, processed to appear at true-color, and were compared with results of sediment analyses using GIS software.

## 2.3 Results and Discussion

### 2.3.1 $^7\text{Be}$ Inventories

Inventories of  $^7\text{Be}$  for May and July sampling periods are shown in Table 1 and Figure 5. Inventories of cores collected 8 May, 2011, the day before spillway opening, were 0.72-4.21 dpm/cm<sup>2</sup> (Table 1). Mean inventory ( $\pm 1\sigma$ ) for this sampling period was  $1.23 \pm 2.01$  dpm/cm<sup>2</sup>.

Inventories of cores collected 12-13 May 2011, four days after the opening of the spillway, were 0.41-0.86 dpm/cm<sup>2</sup> (Table 1). For this survey, the largest inventories occurred near the mouth of the spillway (05-15, 05-20, 07-22, and 10-23), in the area beneath the suspended sediment plume, while the majority of the remaining samples had undetectable levels of <sup>7</sup>Be (Fig. 5a). Mean inventory ( $\pm 1\sigma$ ) for this sampling period was  $0.48 \pm 0.55$  dpm/cm<sup>2</sup>. In July, inventories recorded seventeen days after the closure of the spillway were 0.18-1.48 dpm/cm<sup>2</sup> (Table 1). For this survey, the highest levels were concentrated near the spillway outlet (05-20 and 07-22) and at the northern and southern flanks of the coring grid (15-00, 15-05, 15-10, and 05-00 respectively), whereas samples located in the central portion of the lake contained the lowest inventories (10-00, 10-05, 10-10, 10-15, and 10-20) (Fig. 5b). Mean inventory ( $\pm 1\sigma$ ) for this sampling period was  $0.52 \pm .50$  dpm/cm<sup>2</sup>.

**Table 1.** <sup>7</sup>Be Data Set for the May and July (2011) Surveys\*

Survey/ Station	<sup>7</sup> Be Inventory (dpm cm <sup>-2</sup> )	<sup>7</sup> Be Surface Activity (dpm g <sup>-1</sup> )	<sup>7</sup> Be Penetration Depth (cm)
8 May*			
1	4.21 ± 0.24	0.98 ± 0.35	4
12	0.72 ± 0.07	1.05 ± 0.42	4
15	n.d.	n.d.	
18	n.d.	n.d.	
mean ( $\pm 1\sigma$ )	1.23 ± 2.01		
12-13 May			
05_00	n.d.	n.d.	
05_05	n.d.	n.d.	
05_10	0.47 ± 0.08	0.99 ± 0.36	2
05_15	0.88 ± 0.09	1.90 ± 0.37	2
05_20	1.60 ± 0.13	2.34 ± 0.37	2
07_22	1.58 ± 0.23	1.42 ± 0.42	2
10_00	n.s.	n.s.	
10_05	n.d.	n.d.	

(Table 1 continued)

10_10	$0.57 \pm 0.08$	$1.14 \pm 0.33$	2
10_15	$0.41 \pm 0.08$	$1.17 \pm 0.46$	2
10_20	$0.30 \pm 0.12$	$0.48 \pm 0.37$	2
10_23	$0.86 \pm 0.14$	$0.99 \pm 0.31$	2
10_55	n.s.	n.s.	
15_00	n.s.	n.s.	
15_05	n.s.	n.s.	
15_10	n.d.	n.d.	
15_15	n.d.	n.d.	
20_7.5	n.s.	n.s.	
20_12.5	n.d.	n.d.	
mean ( $\pm 1\sigma$ )	$0.48 \pm 0.55$		
7-8 July			
05_00	$1.46 \pm 0.18$	$1.61 \pm 0.40$	2
05_05	n.d.	n.d.	
05_10	$0.53 \pm 0.08$	$1.36 \pm 0.43$	2
05_15	n.d.	n.d.	
05_20	$1.24 \pm 0.19$	$1.31 \pm 0.41$	2
07_22	$1.48 \pm 0.13$	$1.07 \pm 0.19$	2
10_00	n.d.	n.d.	
10_05	$0.27 \pm 0.07$	$0.78 \pm 0.42$	2
10_10	$0.47 \pm 0.07$	$1.09 \pm 0.35$	2
10_15	$0.20 \pm 0.05$	$0.42 \pm 0.21$	2
10_20	n.d.	n.d.	
10_23	$0.73 \pm 0.20$	$0.74 \pm 0.41$	2
10_55	n.d.	n.d.	
15_00	$1.17 \pm 0.39$	$0.54 \pm 0.36$	2
15_05	$0.83 \pm 0.14$	$1.38 \pm 0.46$	2
15_10	$0.70 \pm 0.09$	$2.02 \pm 0.51$	2
15_15	$0.56 \pm 0.09$	$1.29 \pm 0.41$	2
20_7.5	n.d.	n.d.	
20_12.5	$0.18 \pm 0.08$	$0.46 \pm 0.40$	2
mean ( $\pm 1\sigma$ )	$0.52 \pm 0.50$		

n.s. = not sampled, coring grid size increased for July and August

n.d. = not detected, detection limit of  $\sim 0.25$  dpm g<sup>-1</sup>

\* May 8<sup>th</sup> cores collected by Dr. John White

\* August not represented due to the large amount of precipitation over Lake Pontchartrain in the weeks preceding the survey

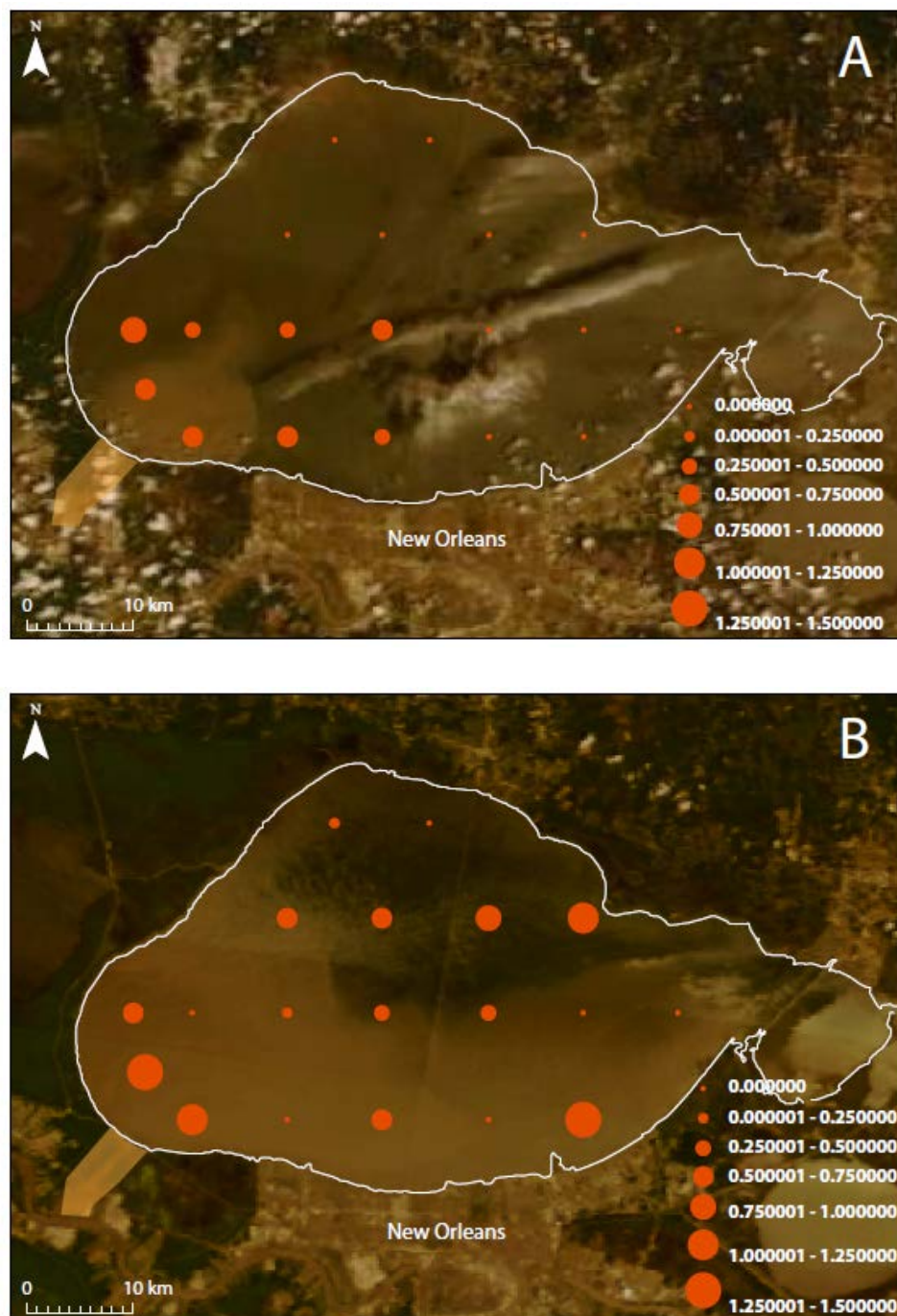


Figure 5.  $^7\text{Be}$  Inventories for the May (a) and July (b) sampling surveys in dpm/cm<sup>2</sup>. (the spillway is highlighted in orange, 11 May 2011 ESL MODIS image for A, 27 May 2011 ESL MODIS image for B)

Inventory change over time can be described by Equation 2, where  $I_t$  is the inventory at time  $t$  (dpm/cm<sup>2</sup>),  $I_o$  is the initial inventory (dpm/cm<sup>2</sup>),  $\lambda$  is the decay constant for <sup>7</sup>Be (1/t), and  $I_n$  is new inventory (dpm/cm<sup>2</sup>).

$$I_t = I_o \exp(-\lambda t) + I_n \quad (2)$$

Potential sources for flux of  $I_n$  to the sediments of Lake Pontchartrain include spillway discharge, discharge from other rivers, vertical atmospheric deposition, and input from coastal waters due to tidal exchange (e.g., Baskaran et al., 1997). Prior to spillway opening, leakage through the spillway from the Mississippi River was estimated at 40 m<sup>3</sup>/s by the USACE for April 2011 (US-ACE, 2011). This leakage may be responsible for the apparent slight elevation in <sup>7</sup>Be inventories measured in cores 1 and 12 collected 8 May, 2011 (Table 1).

NOAA precipitation data for the region and USGS stream gauge data for the period show that May and June 2011 were drought conditions, with minimal water input (either fluvial or precipitation) into Lake Pontchartrain other than the spillway, thus reducing the influence of these mechanisms on changing <sup>7</sup>Be inventories (NOAA, 2012, USGS, 2012). Likewise, tidal exchange for this period was restricted, because of the unusually large Mississippi river water input, and the location of narrow tidal passes to the lake 40 km east of the spillway outlet (Zhang et al., 2012). Mean inventories for both May and July sampling periods are lower than mean historical inventories measured in an estuary 200 km west of our study area (3.1 dpm/cm<sup>2</sup>) (Baskaran et al., 1997), suggesting that our lower measurements may have been influenced by drought conditions that limited rainfall scavenging and river input of <sup>7</sup>Be. We thus suggest that vertical dry deposition of <sup>7</sup>Be to the lake was the primary mechanism for <sup>7</sup>Be delivery prior to the spillway opening, and that a secondary influence was the modest leakage before operation.



As a result, the inventories measured before spillway opening, and after spillway opening in areas not influenced by the suspended sediment plume, represent something near steady-state conditions. This condition could be represented by the expression  $I_n = \bar{I} + \Delta I$ , wherein  $\bar{I}$  represents a quasi-steady inventory sufficient to offset the decay of  $I_0$  (which would be the case if source terms other than spillway discharge were nearly constant for some time before and during our study), and  $\Delta I$  represents inventory increase from May to July, controlled primarily by input from the Bonnet Carré spillway. Because conditions in May and June were not perturbed by large additional  $^7\text{Be}$  input from precipitation or rivers other than the Mississippi, the overall increase in  $^7\text{Be}$  inventories from May to July (Fig. 6) was largely controlled by new sediment input from the Mississippi River, through the spillway.

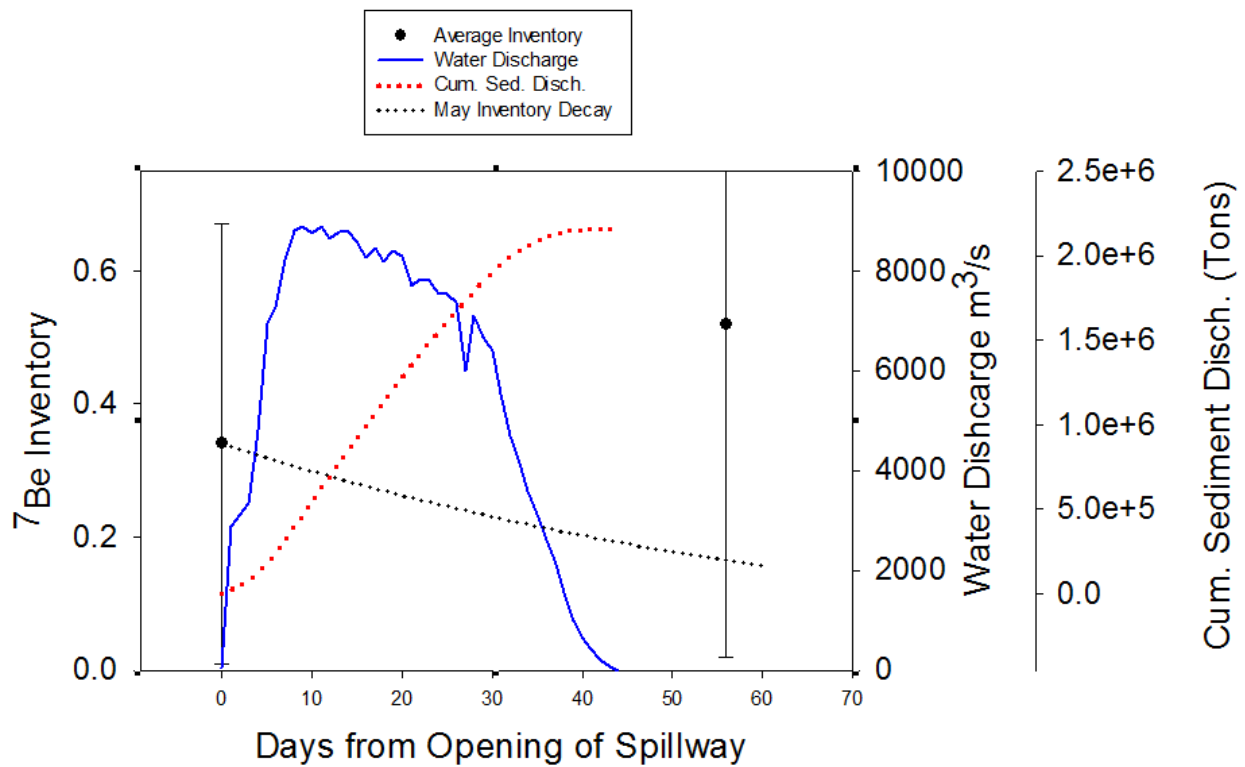


Figure 6. Average  $^7\text{Be}$  Inventory for May and July in Lake Pontchartrain with Water and Cumulative Sediment Discharge through the Bonnet Carré (USGS and US-ACE, 2012)

### 2.3.2 Sediment Flux and Fate

Change in inventory from May to July sampling is displayed in Figure 6 (change in mean inventory) and Figure 7 (map view). Figure 7 displays positive, negative, and neutral differences of the range -0.72 to 1.46 dpm/cm<sup>2</sup>. Spatially, the positive changes in inventory are concentrated near the spillway's mouth, across a broad northern portion of the lake, and in the lake's southeastern corner. Negative changes extend horizontally throughout the central to south central zone of the lake. These inventory changes can be related to sediment flux using Equation 3, assuming all the <sup>7</sup>Be is deposited in adsorbed form with the sediment, where  $M_L$  is new sediment deposition per unit area (g/cm<sup>2</sup>),  $\Delta I$  is the change in inventory from May to July sampling (dpm/cm<sup>2</sup>), and  ${}^7\text{Be}_{A_2}$  is the mean surface activity for July sampling (dpm/g).

$$M_L = \Delta I / {}^7\text{Be}_{A_2} \quad (3)$$

Total deposition of fine sediment ( $M_{\text{tfs}}$ ) during the study period is then the product of  $M_L$  and lake area, which is approximately 1512 square kilometers, estimated from GIS data.

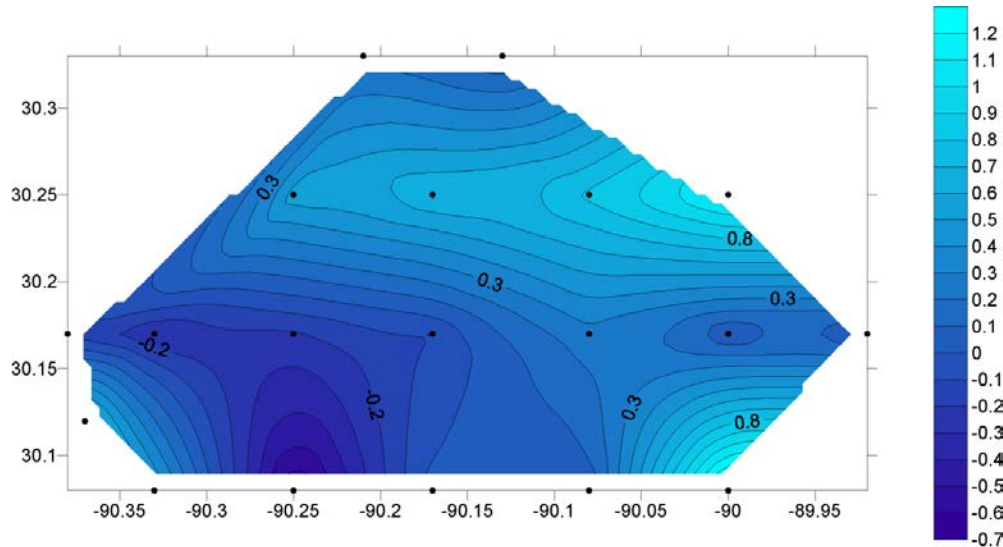


Figure 7. Nearest-neighbor contour plot of change in <sup>7</sup>Be inventory from May to July (dpm/cm<sup>2</sup>). (.1 dpm/cm<sup>2</sup> contour interval)

In order to account for our delayed measurements from the lakewide survey 12-13 May 2011 (in which samples close to the spillway outlet appear to have been influenced by the rapidly spreading plume; Fig. 5a), and compare  $^7\text{Be}$  inventory change to conditions before spillway opening, we substituted the  $^7\text{Be}$  inventories in cores 05-20, 05-15, and 07-22 from the 12-13 May, 2011 survey with the  $^7\text{Be}$  inventory in core 12 from the earlier, 8 May, 2011 survey, which also contains elevated, albeit lower, levels of  $^7\text{Be}$  due to the spillway leakage described above (Table 1). This substitution is intended to minimize the influence of the rapidly dispersing plume (visible in Fig. 5a) on initial  $^7\text{Be}$  inventory estimates. These three cores are closest to core 12 and are the ones most affected by the four days of spillway operation before our first sampling survey (Fig. 4, Table 1). This substitution provides a maximum change in inventory from May to July, whereas mean inventories based on 12-13 May sampling exclusively will provide a minimum estimate of inventory change.

Using the original and substituted changes in mean inventory from May to July (0.4 and .18 dpm/cm<sup>2</sup> respectively), the average surface activity for July, and an area equivalent to the lake's size, Equation 3 gives a range of  $1.1 < M_{\text{tfs}} < 3.8$  million metric tons (Mt) of new muddy suspended sediment that deposited in Lake Pontchartrain from the operation of the spillway, by 8 July 2011. This estimate does not account for coarse sediments within the spillway and proximal to its mouth, which are too coarse to adsorb much  $^7\text{Be}$ , and appear to have deposited mostly between the spillway entrance and station 05-20 in the lake (Chapter 3, Fig. 4)(Nittrouer et al., 2012).

Figure 6 contains daily water and cumulative sediment discharge measurements for the spillway, collected by the USGS and provided by the Louisiana Office of Coastal Preservation and Restoration (B. Vosburg, personal communication). The total sediment discharge of muddy

sediment from these data is estimated at 2.2 Mt (product of water discharge and muddy sediment concentration) for the period of spillway operation (Fig. 6). Considering our uncertainty estimates, the median value for total new sediment deposition in the lake is  $M_{\text{tfs}} \approx 2.45$  Mt, these results suggest that most of the fine sediment delivered by the spillway to the lake was deposited on the lake floor by the time of July sampling. This flux of muddy sediment is  $\sim 10\%$  of the yearly budget to the Wax Lake Delta (Roberts, 1998), and is equivalent to the yearly flux at West Bay ( $\sim 2.6$  Mt/yr), the only other large scale man-made diversion in operation on the lower Mississippi River (Andrus and Bentley 2007).

The distinct spatial variation in the change in inventory from May to July (Fig. 7) most likely represents local erosional and depositional patterns of the newly deposited sediment brought about by strong plume discharge and lake circulation. A zone of low and depleted inventories spans the East-West central portion of the lake, extending approximately from the spillway outlet to tidal passes at the east end of the lake (Fig. 7). MODIS satellite images (Fig. 5B) demonstrate that this area was in fact transited by the suspended sediment plume. Low  $^7\text{Be}$  deposition in this corridor might thus be the result of elevated bed shear stresses (reducing deposition, or enhancing resuspension) rather than from a lack of sediment in the water column. Correspondingly, the areas of inventory gain are likely to be regions of lower average bed-shear stress, and are thus more conducive to sediment deposition.

### **2.3.3 Resuspension**

Resuspension is a major factor related to sediment dispersal in Lake Pontchartrain (Flocks et al., 2009). Wave resuspension calculations estimate that for a 20km fetch, 5m water depth, and grain sizes within the medium to coarse silt range, a threshold wind speed of approximately 7 m/s is needed for there to be a disturbance in the upper centimeter of bedload

sediment (Booth, 2000). With this value, wind data from the NOAA New Canal, LA station (ID: 8761927) shows that there were eight possible resuspension events between the opening and closing of the spillway, and ten between the May and July sampling surveys. These observations suggest that wind-wave resuspension also contributed to sediment dispersal during our study, in addition to plume hydrodynamics, tidal, and wind-driven unidirectional flow (Flocks et al., 2009). However, despite the potential for local resuspension and transport of sediments in Lake Pontchartrain, most fine sediment delivered to the lake appears to have been retained as lake-bed deposits, rather than having been transported out of the system, as happens to 50-75% of sediment delivered to other diversions that have been so studied, such as West Bay, and Wax Lake (Roberts, 1998; Andrus and Bentley, 2007). This difference is likely to be influenced by relative rates of water exchange between the receiving basins for diversion flow and the coastal ocean (e.g., Paola et al., 2011), coupled with local resuspension processes (Walker & Hammack, 2000). Both West Bay, and Atchafalaya Bay, where the Wax Lake delta is located, have relatively open boundaries with the coastal ocean (and more effective water exchange with the coastal ocean), compared to the more fully enclosed boundaries of Lake Pontchartrain, which has only two narrow tidal passes connecting it to the sea.

## **2.4 Implications and Conclusions**

Total fine sediment deposition in Lake Pontchartrain between 8 May and 8 July 2011 is estimated to have been  $2.45 \pm 1.35$  Mt, estimated by changes in  $^7\text{Be}$  inventories. These results compare favorably with 2.2 Mt of fine sediment discharge measured directly in the Bonnet Carré Spillway by the USGS, and suggests that sediment retention within Lake Pontchartrain during this period was near 100%, with respect to sediment input from the spillway. Considering our measurement uncertainty, the lowest estimated trapping efficiencies within Lake Pontchartrain

are comparable to the highest estimates at West Bay (~50%), a man-made diversion north of Southwest Pass in the modern Balize delta lobe (Andrus and Bentley, 2007). This demonstrates that the trapping of fine sediment from diversion flow in more inland, enclosed basins is probably higher than sediment trapping in more open bays with greater connectivity to the coastal ocean. Because up to 90% of suspended sediment available to diversion flow from the Mississippi River is in the mud fraction (Allison and Meselhe, 2010), this represents a large sediment reservoir that can contribute to land building by diversions, and emphasizes the importance of considering receiving basin geometry with respect to maximizing sediment retention from diversion flow.

Louisiana's 2012 Comprehensive Master Plan for a Sustainable Coast indicates that sediment diversions will play a vital role in future coastal restoration projects throughout much of south Louisiana (CPRA, 2012). Even though the Bonnet Carré Spillway was not designed for restoration purposes, and the infilling of Lake Pontchartrain is not one of the Master Plan objectives, this study has demonstrated that diversion flow from the Bonnet Carré Spillway into Lake Pontchartrain constitutes a useful sediment-dispersal analog for the operation of large diversions planned for future development in the Mississippi Delta.

### 3. THE AUGUST SURVEY AND ADDITIONAL SEDIMENTOLOGICAL OBSERVATIONS

#### 3.1 $^7\text{Be}$ Inventories and Precipitation for the August Survey

Initial analysis of  $^7\text{Be}$  for the August survey showed a measurable increase in inventory in comparison to both the May and July sampling periods (Fig. 8). If all other contributing factors other than spillway sediment discharge were in approximate steady state before and after the spillway's closure, the natural decay of  $^7\text{Be}$  should have decreased inventories of the radioisotope in the lake in relation to July.

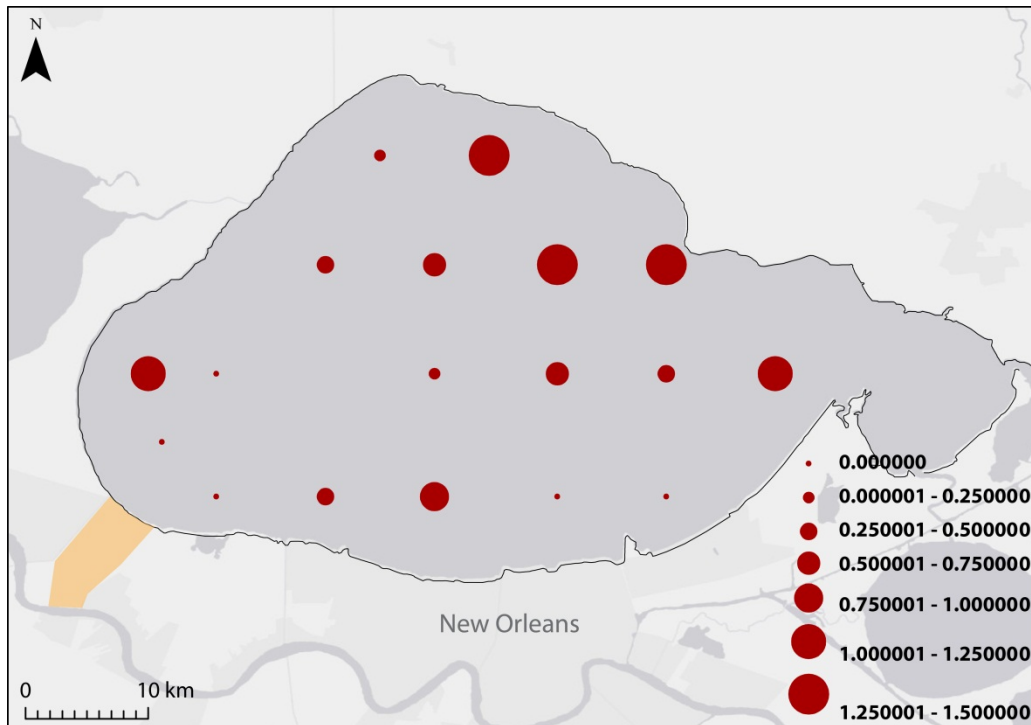


Figure 8.  $^7\text{Be}$  Inventories for the August Sampling Survey in dpm/cm<sup>2</sup>.

Precipitation records show that significant amounts of rain fell directly over and around Lake Pontchartrain in middle to late July and parts of August (NOAA, 2012). In five days (15/07/2011 to 19/07/2011), ~16 cm of rain fell within the boundaries of the lake (Fig. 9). In addition, river stage for small rivers that feed into Lake Pontchartrain increased during this time period (USGS, 2012), most likely due to precipitation from these storm events (see Appendix C).



Research shows that large storm events can deposit significant amounts of  $^7\text{Be}$  relative to other localized depositional processes (Baskaran et al., 1993 and 1997). The increase in inventory from July to August can thus be attributed to the influx of large amounts of rainwater into the basin between the two sampling periods, in contrast to the lack of such abundant precipitation between our May and July sampling events.

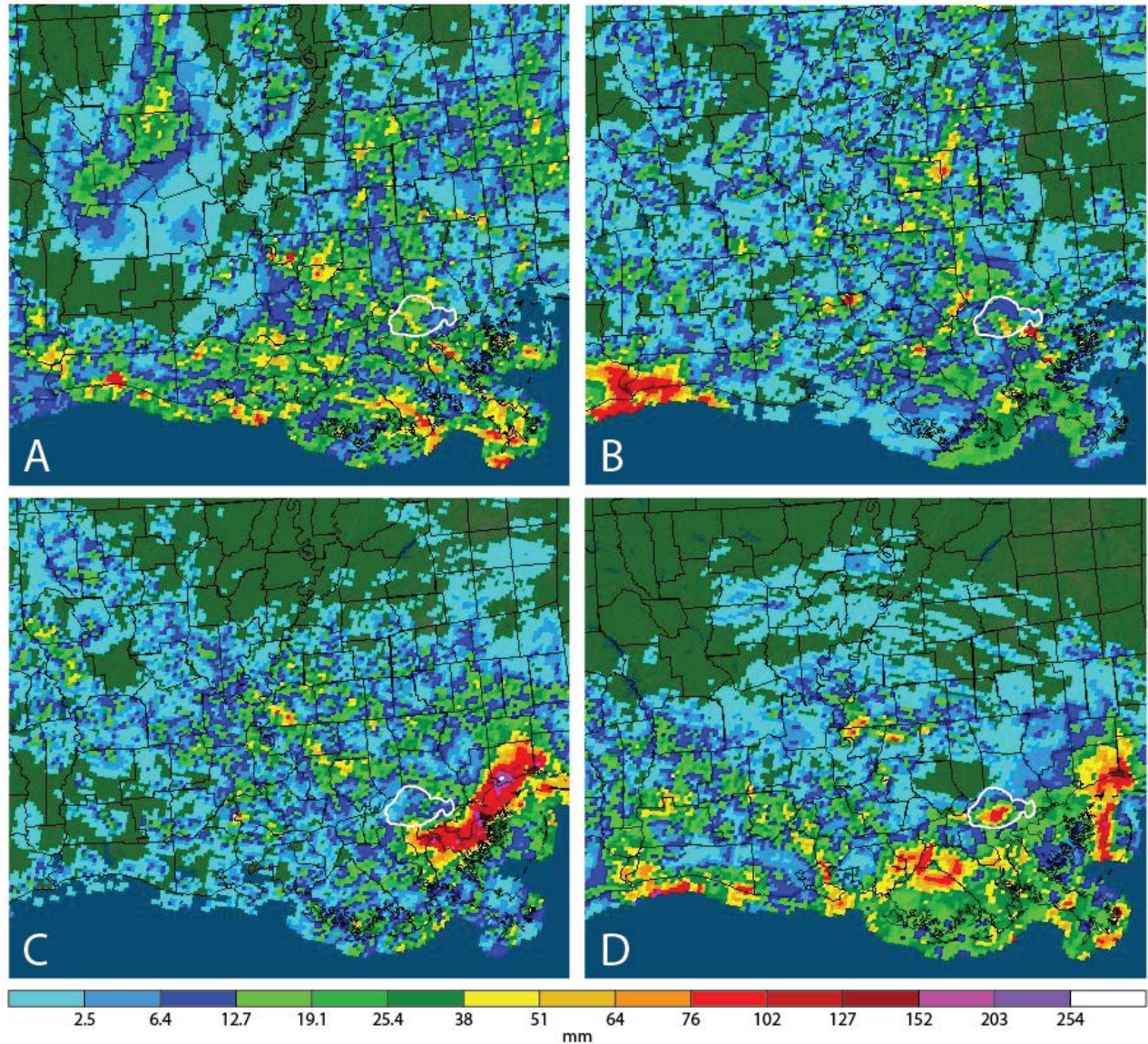


Figure 9. Precipitation for 15/07/2011 (a), 16/07/2011 (b), 18/07/2011 (c), and 19/07/2011 (d). Lake Pontchartrain is highlighted in white. (NOAA, 2012)



### 3.2 Grain Size Analysis

The upper-most 2cm of seabed had average grain sizes within the fine to medium silt range before, during, and after the operation of the spillway (Fig. 10). The finest grain sizes for all three surveys were very fine grained silts, and the coarsest samples were very fine grained sands (see Appendix D).

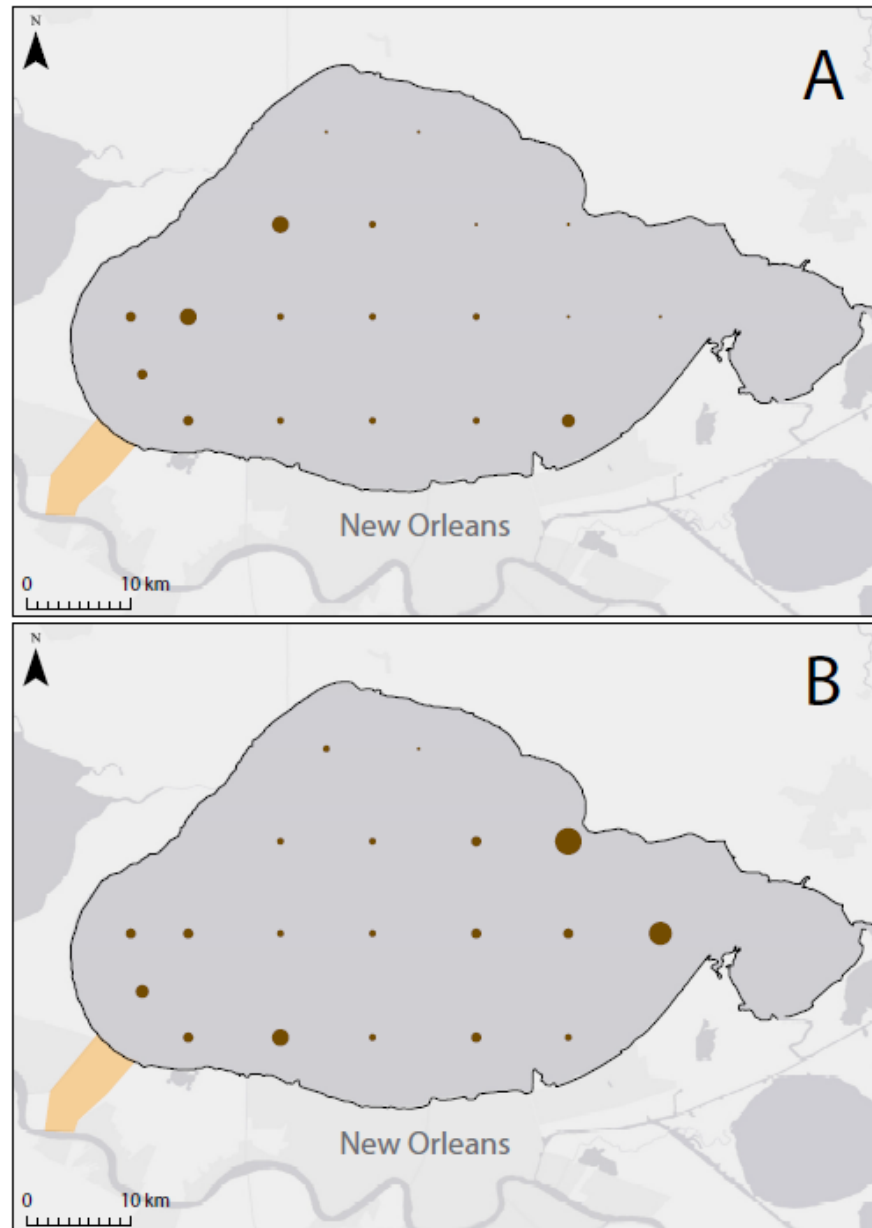
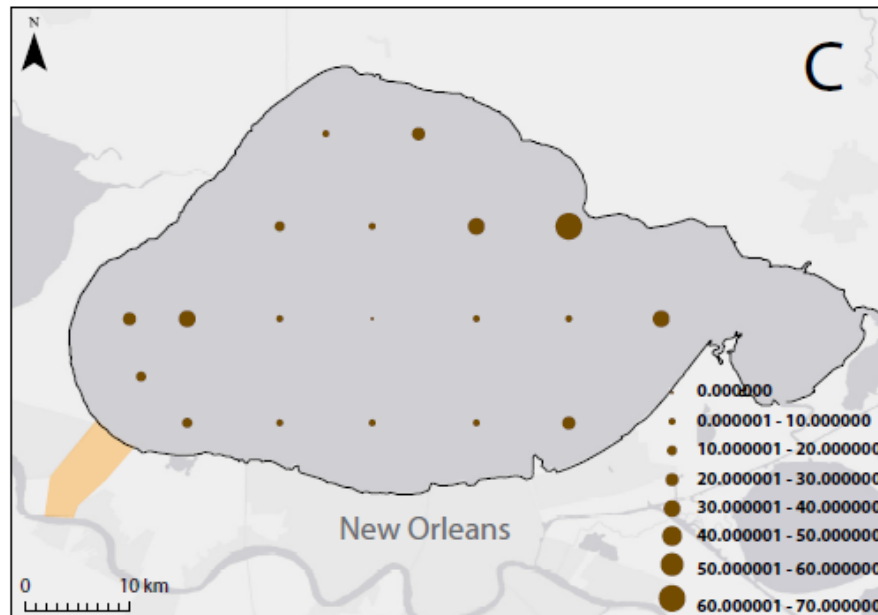


Figure 10. Top 2cm Grain Sizes ( $\mu\text{m}$ ) for the May (a), July (b), and August (c) Sampling Surveys. (0 = not sampled)

(Fig. 10 continued)



Spatially, Figure 9a illustrates that some of the coarsest sediments on the lake floor occur near the spillway outlet. This is probably caused in part by proximal deposition of the spillway's bedload. In July and August, the medium to coarse silt deposits seen near the spillway in May are still present, but very fine sand is now seen in select cores from the Northeastern portion of the lake (Figs. 9b&c). One potential explanation for this is the selective removal of the finer grained fraction over time by wave-induced resuspension, previously shown to be a major sediment transport factor by Flocks et al. (2009) in this specific area. Another explanation is that after the spillway related layer of sediment was deposited, smaller rivers that enter the lake could once again be one of the dominant sedimentation drivers in this area and deposit the coarser sediments from their source basins north of Lake Pontchartrain in the Pleistocene terraces (Flocks et al., 2009).

### 3.3 X-radiography

Visually discriminating the freshly deposited sediment layer using x-radiography is difficult due to the fact that the  $^7\text{Be}$  related sediment's grain sizes over much of the lake in this study are analogous to grain sizes seen in the lake's top layer in the past (Flocks et al., 2009). In addition, the average sediment flux calculated in Chapter 2.3.2 creates a layer that is less than 2mm thick when spread evenly across the entire lake. Even so, some important features can still be seen using x-radiography, especially near the mouth of the spillway.

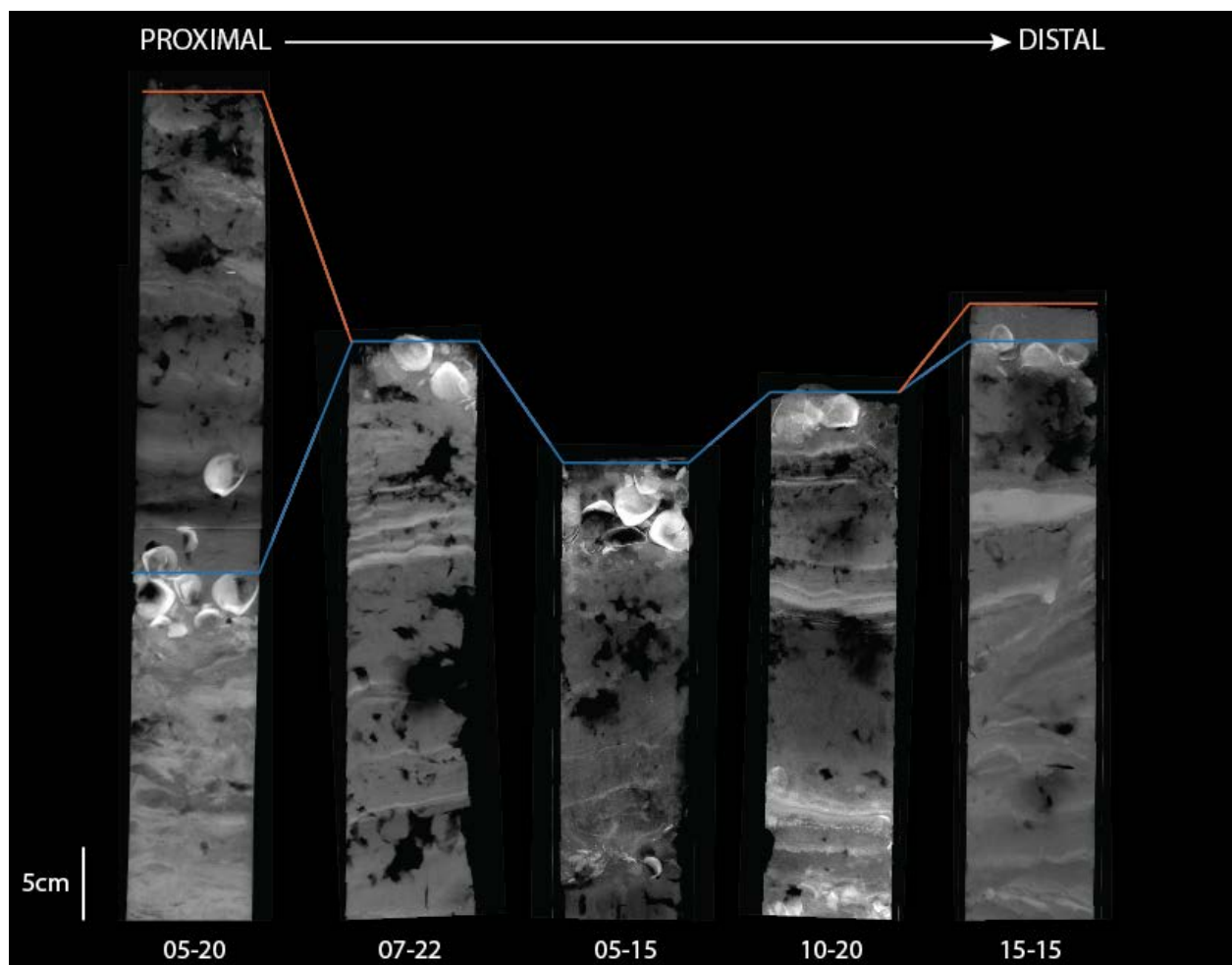


Figure 11. X-radiography for July. Inferred top of pre-spillway lake sediment in blue, top of spillway related sediment in orange.

Using a fairly continuous shell layer as the inferred top of pre-spillway sediment in Lake Pontchartrain, x-radiography of cores from the July sampling period indicates that a ~35cm layer of spillway related sediment was deposited at station 05-20, which is near the Bonnet Carré's outlet and re-affirms that early, small scale delta building processes were occurring proximal to the spillway's mouth over its operational timeframe (Fig. 11). Stations 07-22, 05-15, and 10-20 are located further from the spillway and did not contain identifiable new sediment deposits in x-radiography (Fig. 11). These more distal samples correspond to neutral or negative changes in  $^7\text{Be}$  inventory from May to July, which implies that fresh deposition was either mostly removed or was not very substantial between the two sampling periods at these locations (Fig. 7). In contrast, station 15-15 contains an interpreted new sediment layer that is ~2cm thick and relates favorably to the positive inventory changes seen at this station from May to July in Figure 7 (Fig. 11).

Another key obstacle related to the use of x-radiography for geologic analysis of Lake Pontchartrain is the fact that the lake has been dredged and mined for shells and sediment since the 1930's (Flocks et al., 2009). These disturbances will drastically affect the deeper stratigraphic profiles at certain stations and will presumably make correlating across the lake a very difficult task. Shallower deposits related to the Bonnet Carré's most recent opening are thought to be mostly unaffected by humans due to the close proximity of its operation and our sampling, but, outside of the thick sediment layer seen near the spillway's mouth, most of the new deposits are not unique enough to be easily distinguishable using just grain size and x-radiography. All in all, this re-emphasizes the importance of the use of  $^7\text{Be}$  as a sediment deposition tracer in situations where physical sedimentology may not provide quantifiable answers.

## 4. FUTURE OUTLOOK

### 4.1 Louisiana's Master Plan

Louisiana's Comprehensive Master Plan for a Sustainable Coast is a coastal restoration planning document produced by the Louisiana State Government's Coastal Protection and Restoration Authority (CPRA). The Master Plan documents that Louisiana has lost close to 5,000 km<sup>2</sup> of land in the last eighty years, and could potentially lose a similar amount of land over the next fifty years if no action is taken (CPRA, 2012). To combat this, the plan outlines multiple strategic projects and analyzes their potential impact on remediating land loss while also taking into account their cost. In relation to diversions, the planning committee tested multiple scenarios. Ultimately, they show that even the best set of non-diversion projects reduces the overall land building potential by 881-1649 km<sup>2</sup> when compared to their "maximum" land building scenario, which includes both large and small scale sediment diversions (CPRA, 2012). Figure 12 illustrates this disparity and indicates that the "maximize land" scenario could decrease the amount of land loss by half over the next fifty years in comparison to the no diversion scenario (CPRA, 2012). In summary, they say, "these results indicate that sustainable restoration of our coast without sediment diversions is not possible" (CPRA, 2012 pg. 102).

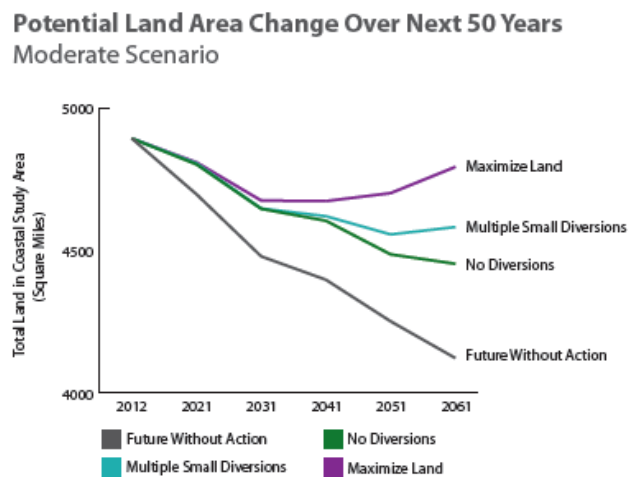
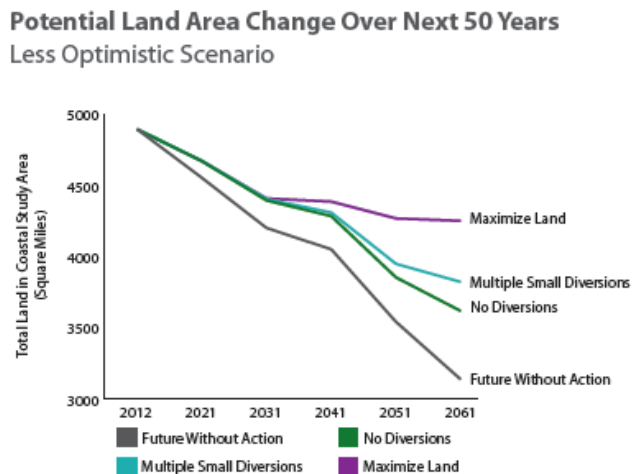


Figure 12. 50 Year Land Area Change Scenarios (CPRA, 2012)

(Fig. 12 Continued)



In addition, the plan demonstrates that diversions have by far the best land building to price ratio when compared to other proposed restoration projects (Fig. 13).

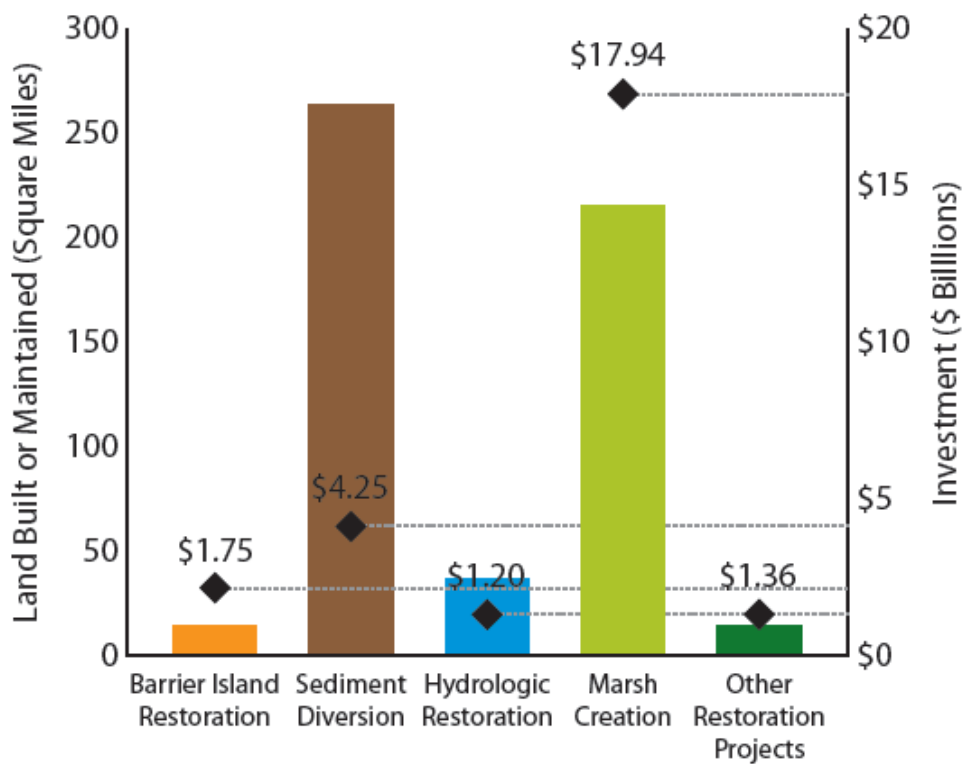


Figure 13. Land Building and Investment Over 50 Years by Project (CPRA, 2012).

## **4.2 Overall Conclusions**

One of the major conclusions of the 2012 Master Plan is that diversions will be one of the main methods utilized in future coastal restoration. Until now, no previous study has documented the muddy sediment delivery potential of a man-made river diversion at this scale. The results presented here indicate that even a large scale man-made diversion not designed for coastal restoration purposes can deliver sediment fluxes on the order of existing large diversions and natural subdeltas in the Mississippi Delta if operated on a regular basis during high flows when both sediment concentration and discharge are highest. In addition, results herein demonstrate that receiving basin geometry and boundaries are important factors in maximizing the land building potential of an engineered diversion, due to the abundance of finer grained sediment in the river and the variability in trapping efficiencies throughout the delta plain.

## REFERENCES

- Allison, M.A., Meselhe, E.A., 2010. The use of large water and sediment diversions in the lower Mississippi River (Louisiana) for coastal restoration. *Journal of Hydrology*, 387: 346-360.
- Andrus T.M., Bentley S.J., 2007. *Sediment Flux and Fate in the Mississippi River Diversion at West Bay: Observation Study*. New Orleans: Amer. Soc. Civ. Eng. 55 pp.
- Barras JA, Padgett WC, Sanders CB. 2009. *Aerial and Bathymetric Spatial Change Analysis of the West Bay Sediment Diversion Receiving Area, Louisiana for U.S. Army Engineer District, New Orleans (MVN) Report*, U.S. Army Eng. Res. Dev. Cent., Environ. Lab, Baton Rouge, La.
- Barry, J.M., 1997. *Rising Tide: The Great Mississippi Flood of 1927 and how it Changed America*. New York, NY: Simon & Schuster.
- Baskaran, M., C.H. Coleman, and P.H. Santschi, 1993. Atmospheric depositional fluxes of  $^7\text{Be}$  and  $^{210}\text{Pb}$  at Galveston and College Station, Texas. *Journal of Geophysical Research*. 98(11):20,555-571.
- Baskaran, M., M. Ravichandran, and T. S. Bianchi, 1997. Cycling of  $^7\text{Be}$  and  $^{210}\text{Pb}$  in a High DOC, Shallow, Turbid Estuary of South-east Texas. *Estuarine, Coastal and Shelf Science*, v. 45, p. 165-176.
- Blum MD, Roberts HH. 2009. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nat. Geosci.* 2:488–91
- Booth, J.G., Miller, R.L., McKee, B.A., Leathers, R.A. 2000. Wind-induced bottom sediment resuspension in a microtidal coastal environment. *Continental Shelf Research* 20:785-806
- Coastal Protection and Restoration Authority (CPRA). 2012. *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Baton Rouge, LA
- Coleman, J.M., Gagliano, S.M., 1964. Cyclic Sedimentation in the Mississippi River Delta Plain. *Transactions Gulf Coast Association of Geological Societies*, 14, 67-80.
- Coleman JM. 1988. Dynamic changes and processes in the Mississippi River delta. *Geol. Soc. Am. Bull.* 100:999–1015
- Corbett, R., Dail, M., McKee, B., 2007. High-frequency time-series of the dynamic sedimentation processes on the western shelf of the Mississippi River delta: *Continental Shelf Research*, v. 27, p. 1600-1615
- Day JW Jr, Boesch DF, Clairain EJ, Kemp GP, Laska SB, et al. 2007. Restoration of the Mississippi Delta: lessons from Hurricanes Katrina and Rita. *Science* 315:1679–84

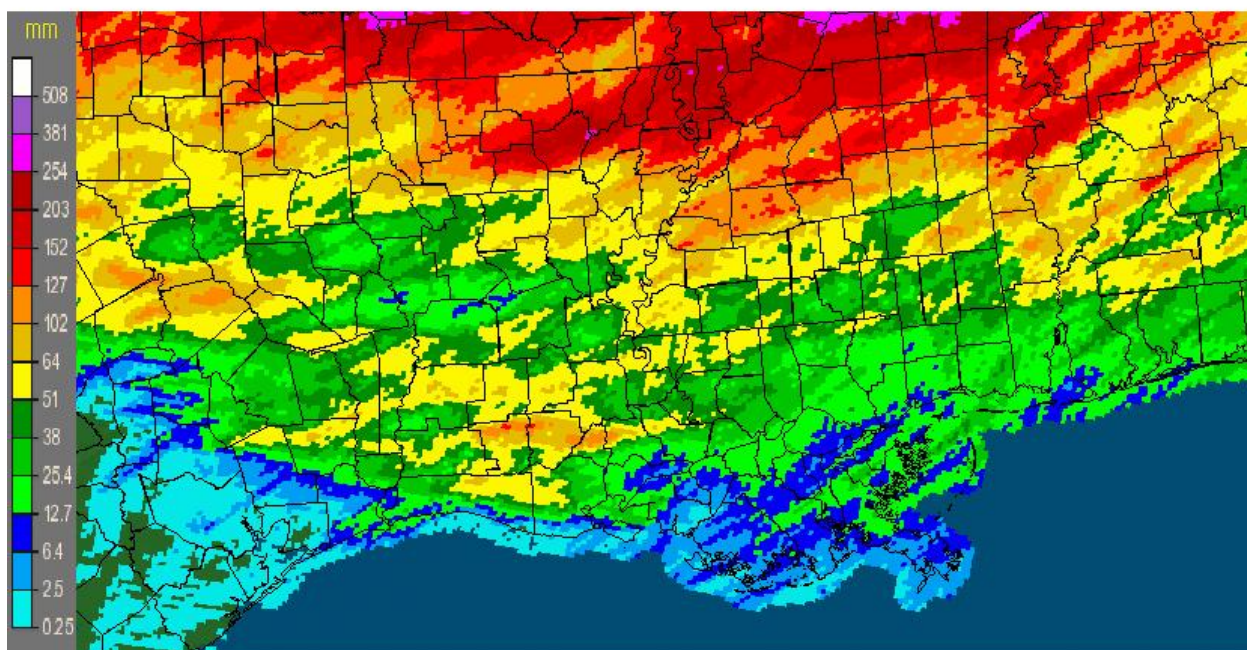


- Day JW, Cable JE, Cowan JH Jr, DeLaune R, Fry B, et al. 2009. The impacts of pulsed reintroduction of river water on a Mississippi Delta coastal basin. *J. Coast. Res.* 54:225–43
- Fisk, H.N. 1944. Geological Investigation of the Alluvial Valley of the Lower Mississippi River. *Miss. River Comm., Vicksburg.*
- Fisk, H.N. 1952. Geological Investigations of the Atchafalaya Basin and the Problem of Mississippi River Diversion. *U.S. Corps of Engineers, Waterways Expt. Sta., Vicksburg.*
- Flocks, J., Kindinger, J., Marot, M., Holmes, C., 2009. Sediment Characterization and Dynamics in Lake Pontchartrain, Louisiana. *J. Coast. Res.* 54:113-126
- Kim W, Mohrig D, Twilley R, Paola C, Parker G. 2009b. Is it feasible to build new land in the Mississippi River Delta? *Eos Trans. AGU* 90:373–74
- McPhee, John, 1989. *The Control of Nature*. New York: Farrar, Straus and Giroux.
- Miller G. 2004. Mississippi River—West Bay sediment diversion. In *World Water and Environmental Resources Congress 2004: Critical Transitions in Water and Environmental Resources Management*, ed. G Sehlke, DF Hayes, DK Stevens, pp. 1–9. Am. Soc. Civ. Eng., Reston, Virg.
- National Oceanic and Atmospheric Administration (NOAA), 2012. National Weather Service Advanced Hydrologic Prediction Service. <http://water.weather.gov/precip/>
- Nittrouer, J.A., Viparelli, E., Parker, G., Mohrig, D., 2012. Backwater hydraulics and sediment transport in coastal fluvial systems: observation and modeling from the Mississippi River. *Ocean Sciences Annual Meeting Abstract Book*, p. 342
- Olsen, C.R., I.L. Larsen, P.D. Lowrey, and N.H. Cutshall. 1986. Geochemistry and deposition of <sup>7</sup>Be in river, estuarine and coastal waters. *Journal of Geophysical Research*, 91(C1): 896-908.
- Paola C, Twilley RR, Edmonds DA, Kim W, Mohrig D, Parker G, Viparelli E, Voller VR. 2011. Natural Processes in Delta Restoration: Application to the Mississippi Delta. *Annu. Rev. Mar. Sci.* 3:67-91
- Roberts HH. 1997. Dynamic changes of the Holocene Mississippi River Delta plain: the delta cycle. *J. Coast. Res.* 13:605–27
- Roberts HH. 1998. Delta switching: early responses to the Atchafalaya River diversion. *J. Coast. Res.* 14:882–99
- Roberts HH, Coleman JM, Bentley SJ, Walker N. 2003. An embryonic major delta lobe: a new generation of delta studies in the Atchafalaya-Wax Lake Delta system. *Trans. Gulf Coast Assoc. Geol. Soc.* 53:690–703

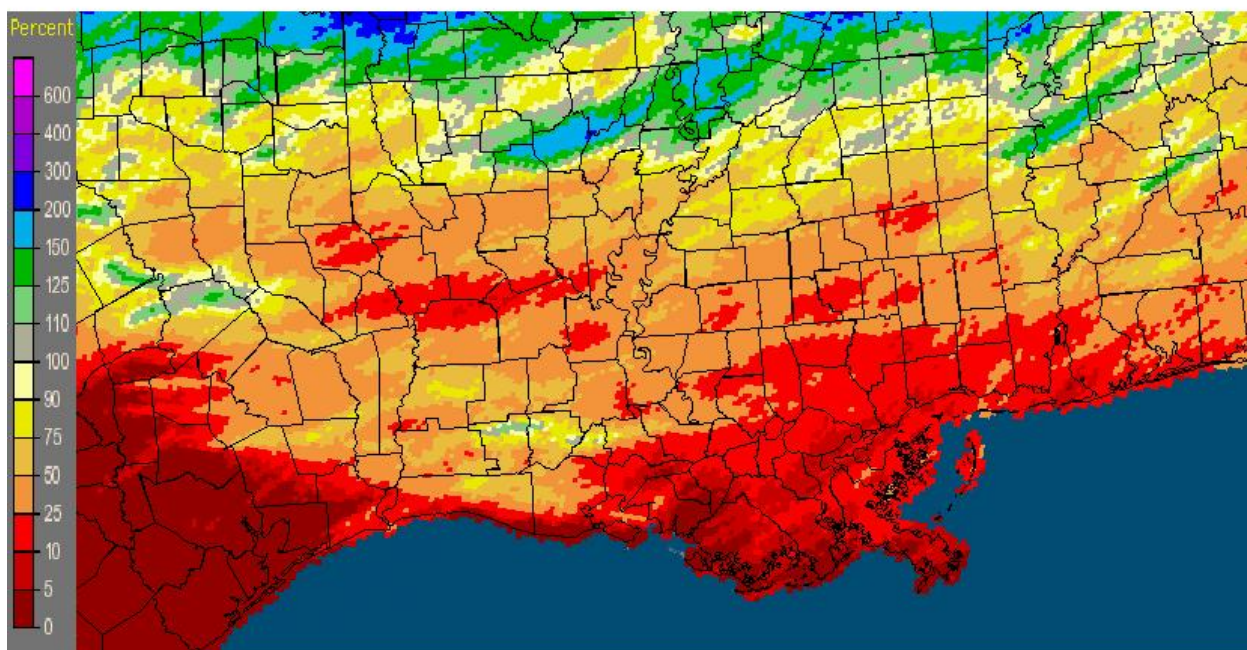
- Rotondo, K.A., and Bentley, S.J., 2003. Deposition and resuspension of fluid muds on the western Louisiana inner continental shelf: Gulf Coast Association of Geological Societies Transactions, v. 53, p. 722-731.
- Russell, R.J. 1936. Physiography of the Lower Mississippi River Delta. *Reports on the Geology of Plaquemines and St. Bernard Parishes, La. State Department Conserv., Geol Bull.* 8:3-199
- Snedden GA, Cable JE, Swarzenski C, Swenson E. 2007. Sediment discharge into a subsiding Louisiana deltaic estuary through a Mississippi River diversion. *Estuar. Coast. Shelf Sci.* 71:181-93
- Sommerfield, C.K., Nittrouer, C.A., and Alexander, C.R., 1999.  $^{7}\text{Be}$  as a tracer of flood sedimentation on the northern California margin. *Continental Shelf Research* v. 19, p. 335-361.
- U.S. Army Corps of Engineers (US-ACE), 2011. Mississippi River Flood Control. <http://www.mvn.usace.army.mil/bcarre/missriver.asp>
- United States Geological Survey (USGS), 2012. National Water Information System. <http://waterdata.usgs.gov/nwis>
- Walker, N.D., and Hammack, A.D., 2000, Impacts of winter storms on circulation and sediment transport: Atchafalaya-Vermillion Bay region, Louisiana, U.S.A: *Journal of Coastal Research*, v. 16, p. 996-1010.
- Zhang, C., Li, C., Bentley, S.J., Walker, N., Bargu, S., White, J.R., Roy, E., Liu, B., Rouse, L.J., 2012. Impact of freshwater diversion on the flushing of Lake Pontchartrain and coastal ocean. *Ocean Sciences Annual Meeting Abstract Book* p. 521-522

## APPENDIX A: PRECIPITATION DATA

Louisiana: April, 2011 Monthly Observed Precipitation  
Valid at 5/1/2011 1200 UTC- Created 7/6/11 15:23 UTC



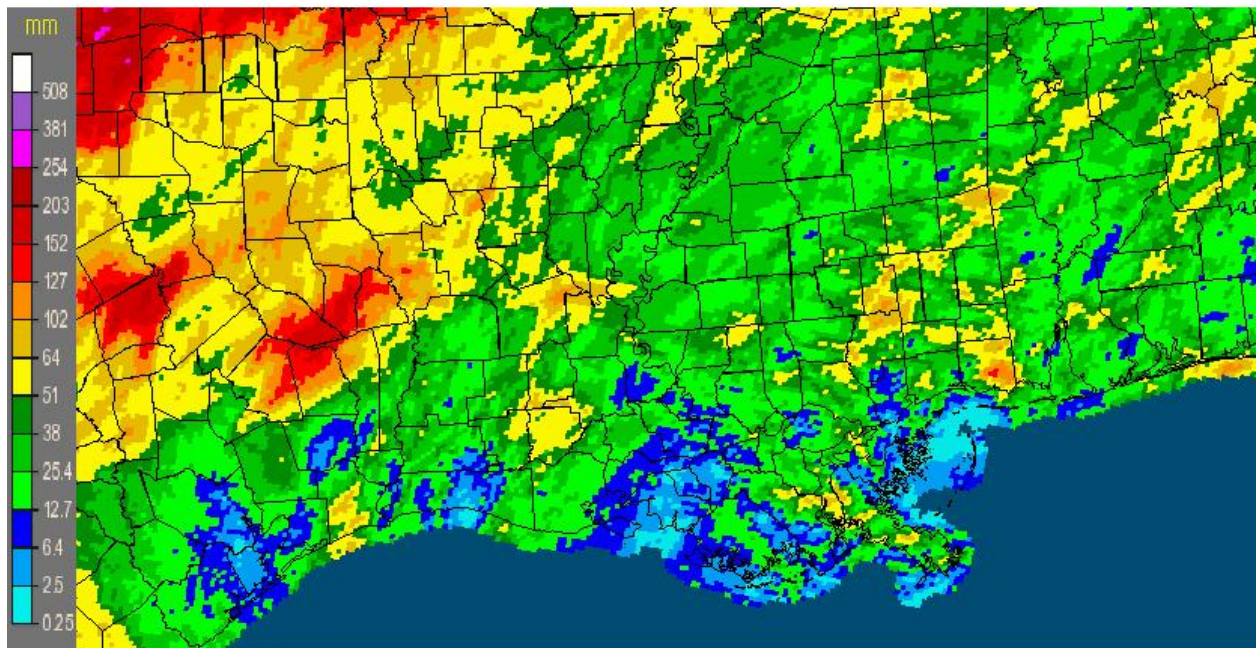
Louisiana: April, 2011 Monthly Percent of Normal Precipitation  
Valid at 5/1/2011 1200 UTC- Created 7/6/11 15:26 UTC



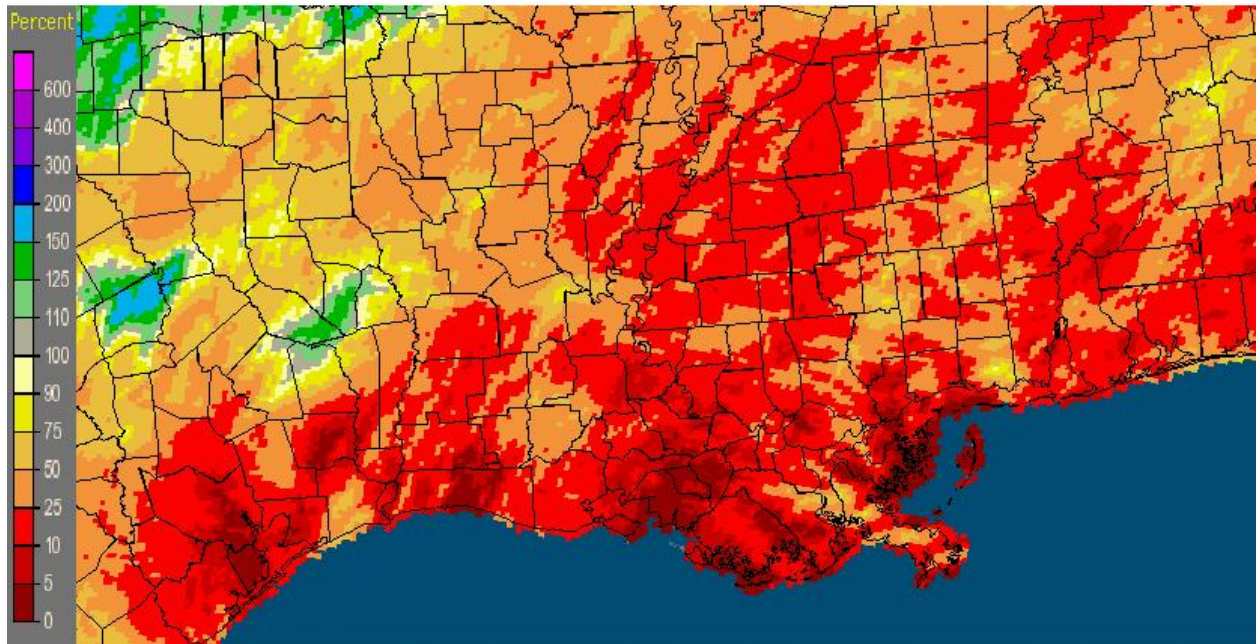
B1: Total and Percent of Normal Precipitation for April, 2011 (NOAA)



Louisiana: May, 2011 Monthly Observed Precipitation  
Valid at 6/1/2011 1200 UTC- Created 6/3/11 21:37 UTC



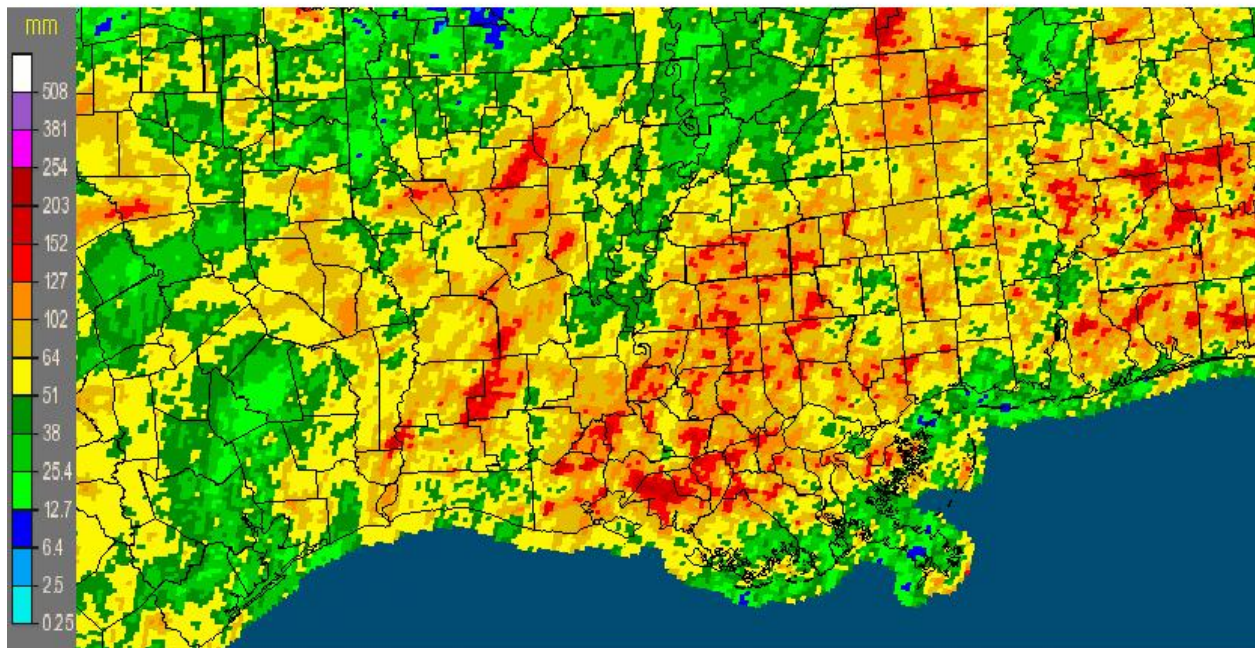
Louisiana: May, 2011 Monthly Percent of Normal Precipitation  
Valid at 6/1/2011 1200 UTC- Created 6/3/11 21:41 UTC



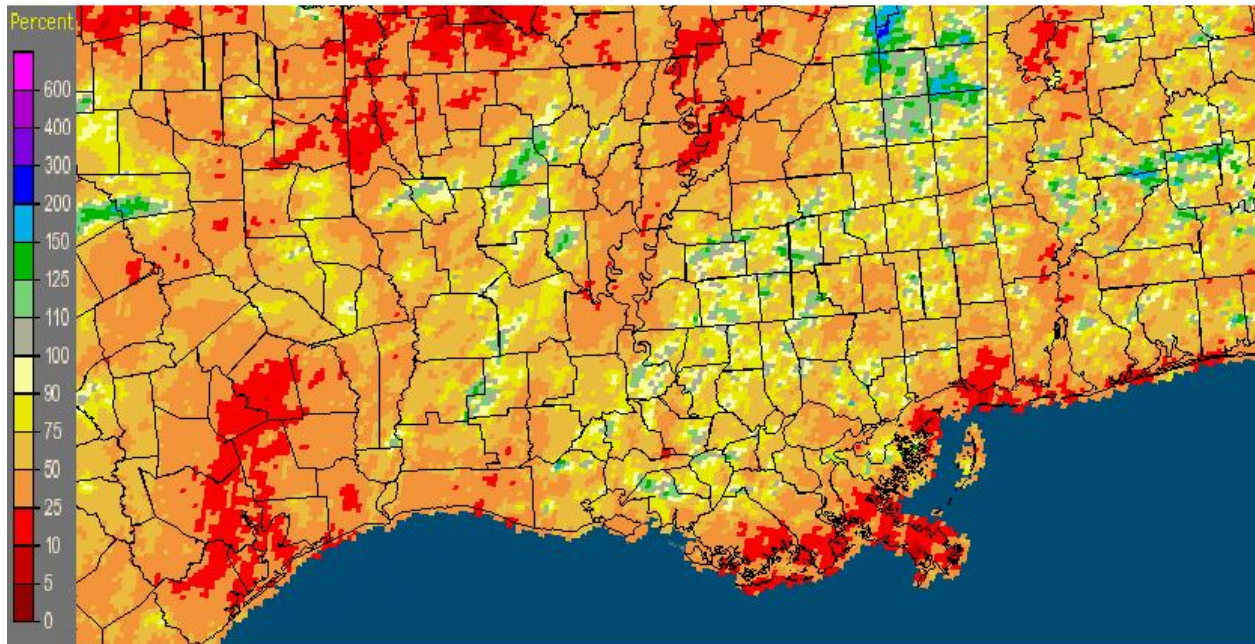
B2: Total and Percent of Normal Precipitation for May, 2011 (NOAA)



Louisiana: June, 2011 Monthly Observed Precipitation  
Valid at 7/1/2011 1200 UTC- Created 7/3/11 21:37 UTC



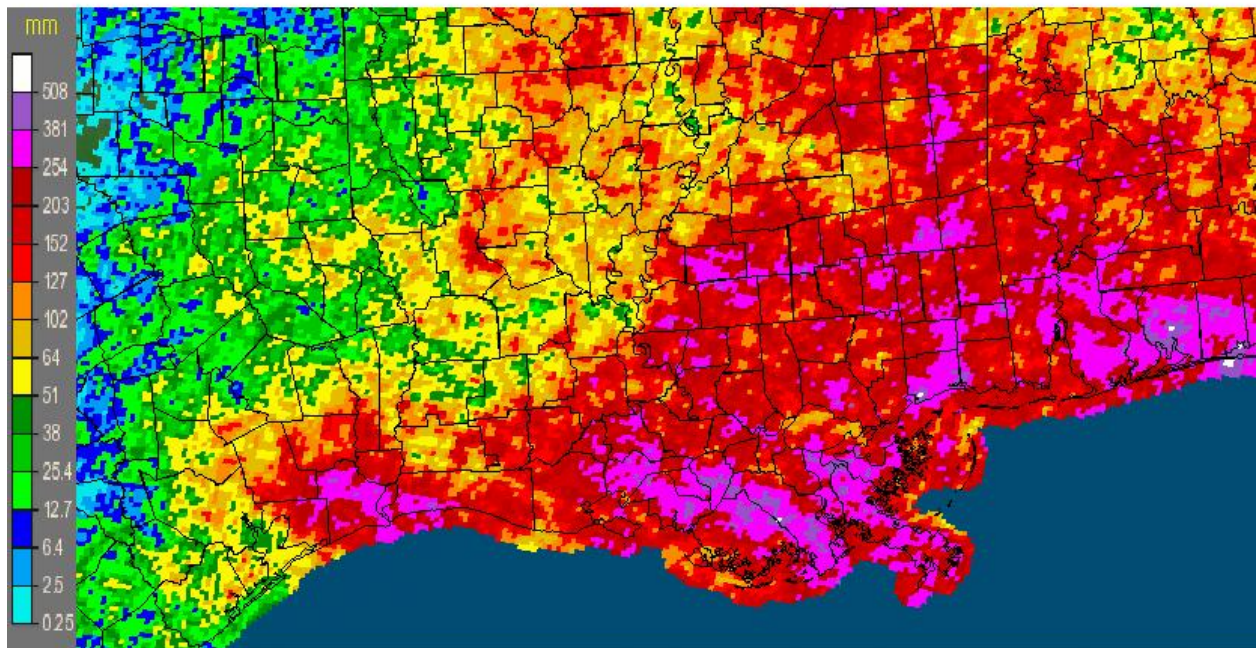
Louisiana: June, 2011 Monthly Percent of Normal Precipitation  
Valid at 7/1/2011 1200 UTC- Created 7/3/11 21:41 UTC



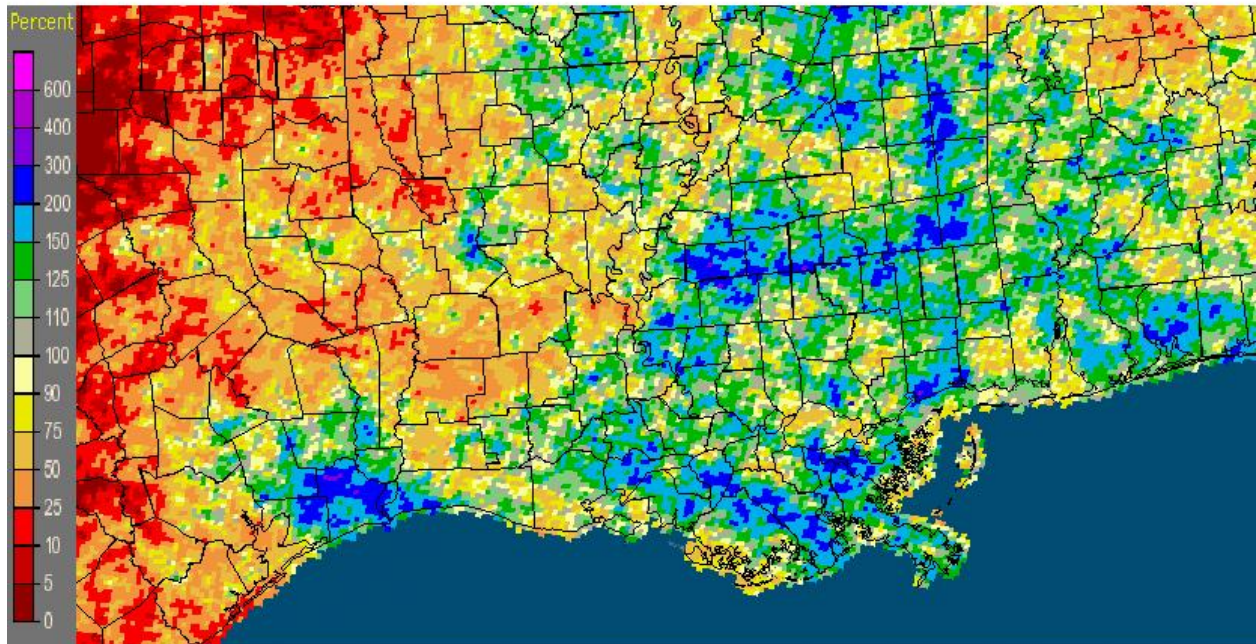
B3: Total and Percent of Normal Precipitation for June, 2011 (NOAA)



Louisiana: July, 2011 Monthly Observed Precipitation  
Valid at 8/1/2011 1200 UTC- Created 8/3/11 21:38 UTC



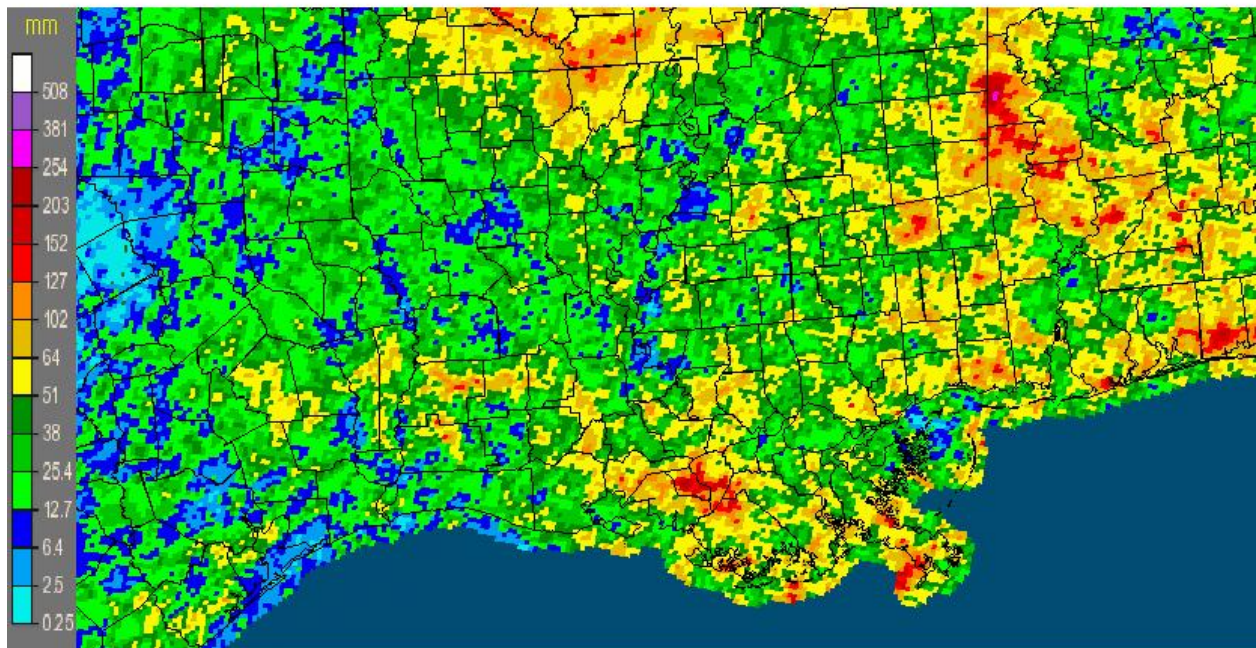
Louisiana: July, 2011 Monthly Percent of Normal Precipitation  
Valid at 8/1/2011 1200 UTC- Created 8/3/11 21:41 UTC



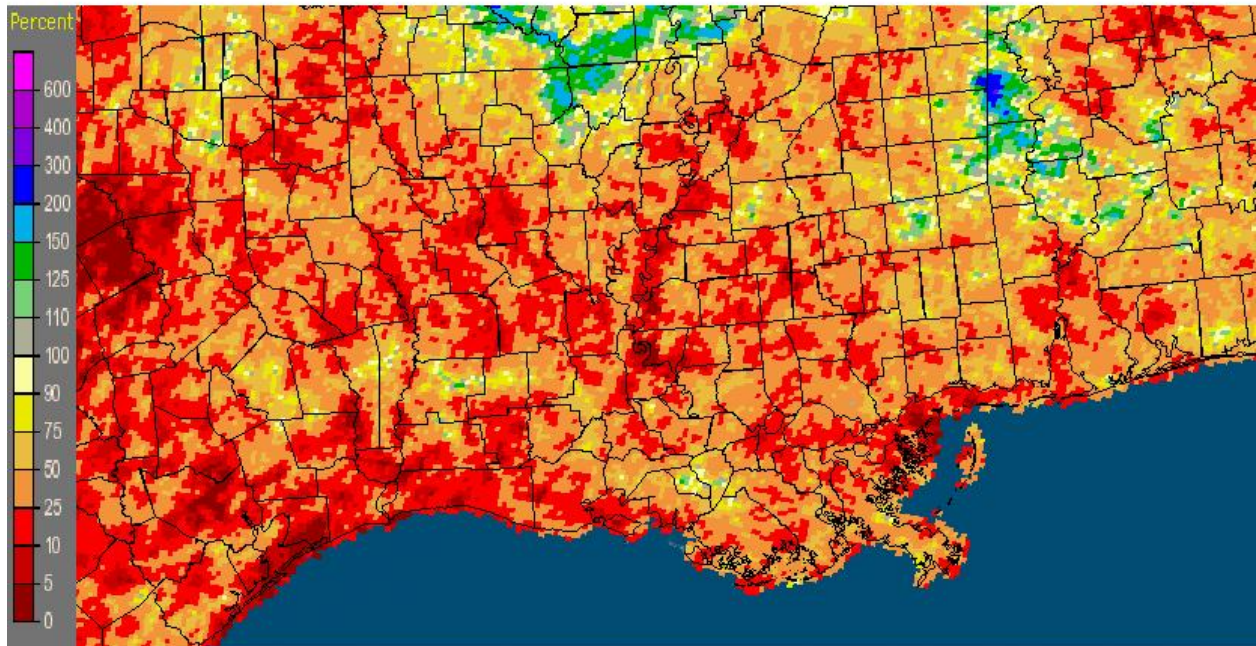
B4: Total and Percent of Normal Precipitation for July, 2011 (NOAA)



Louisiana: August, 2011 Monthly Observed Precipitation  
Valid at 9/1/2011 1200 UTC- Created 9/3/11 21:38 UTC

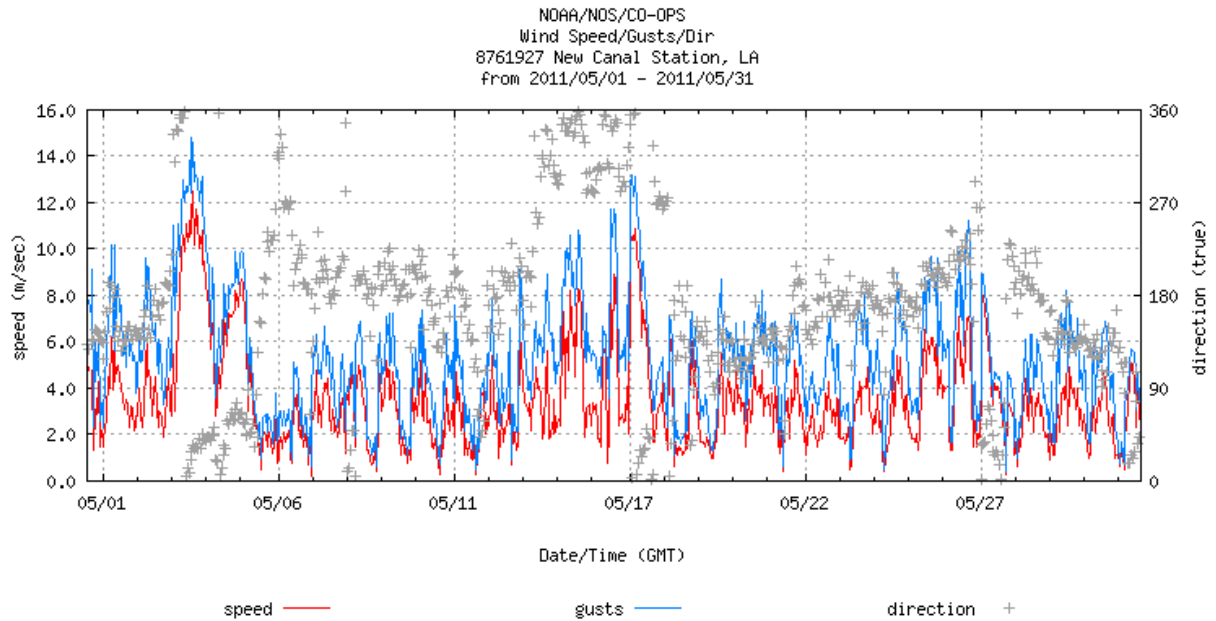


Louisiana: August, 2011 Monthly Percent of Normal Precipitation  
Valid at 9/1/2011 1200 UTC- Created 9/3/11 21:41 UTC

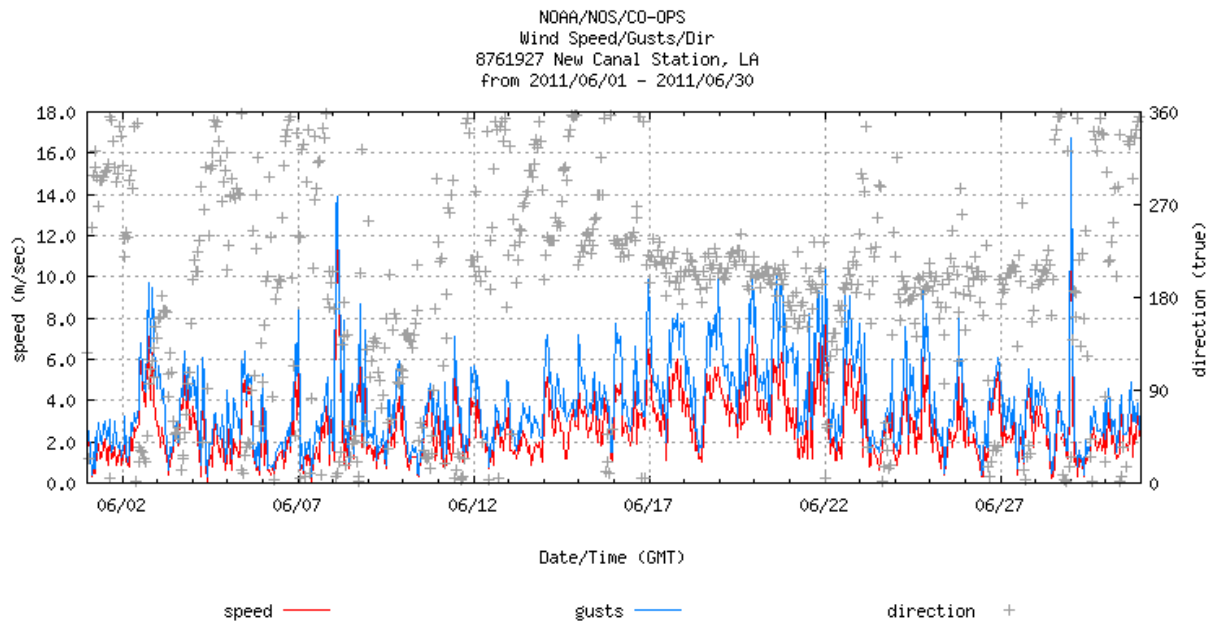


B5: Total and Percent of Normal Precipitation for August, 2011 (NOAA)

## APPENDIX B: WIND DATA

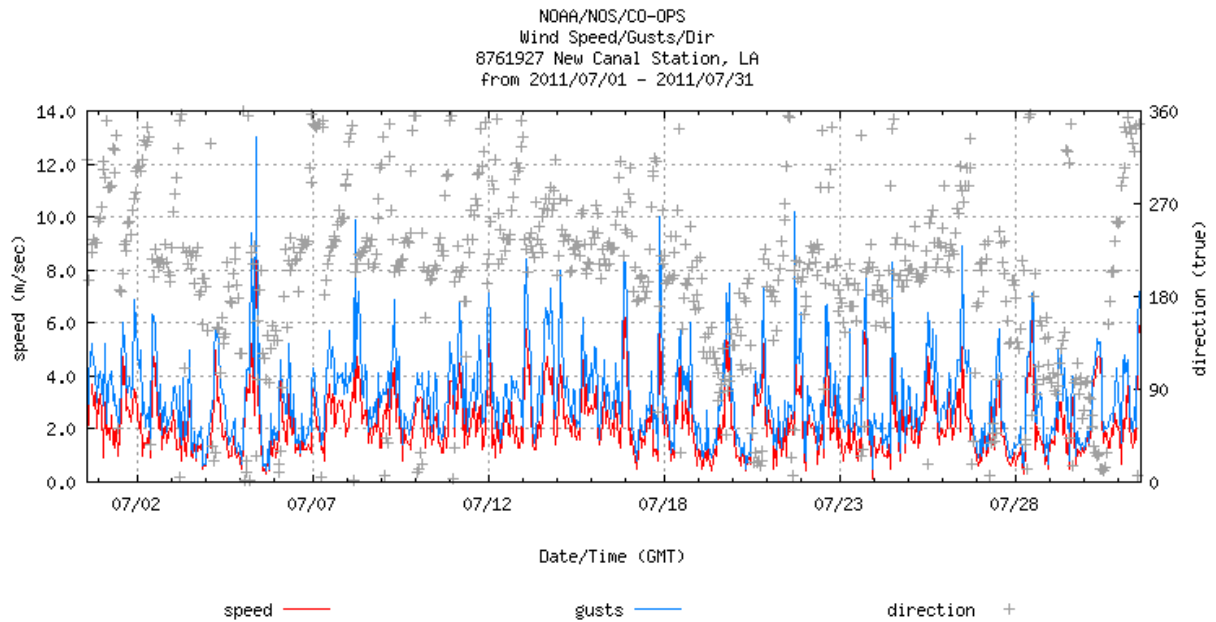


C:1 Wind Speed and Direction from the New Canal, LA NOAA station for May, 2011

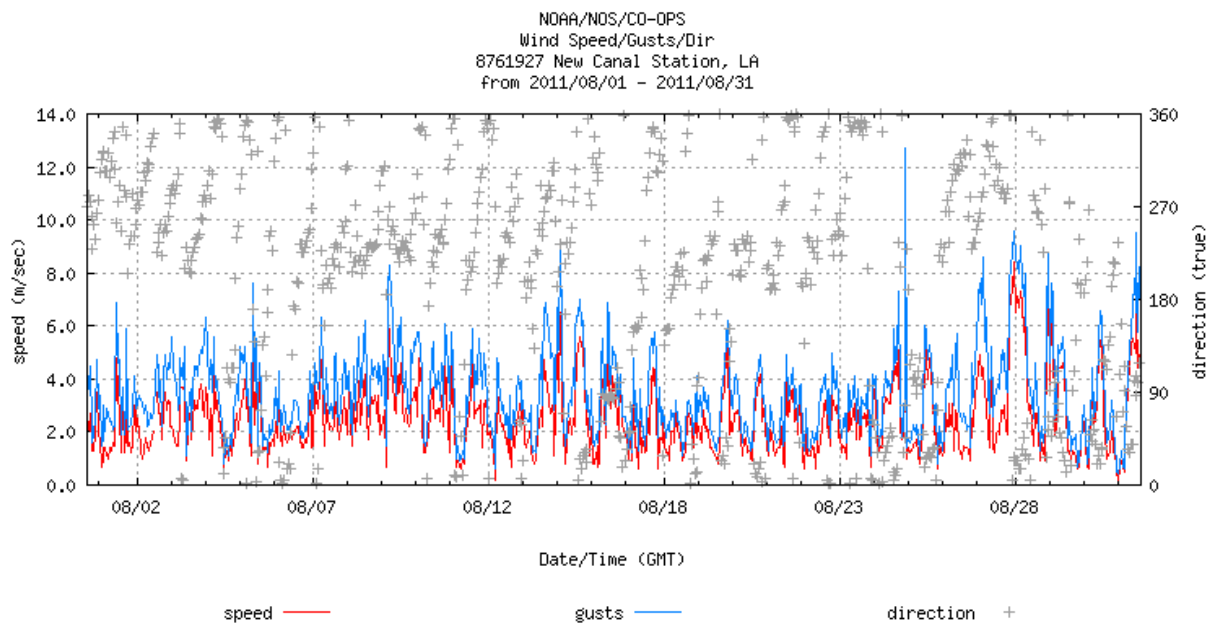


C:2 Wind Speed and Direction from the New Canal, LA NOAA station for June, 2011



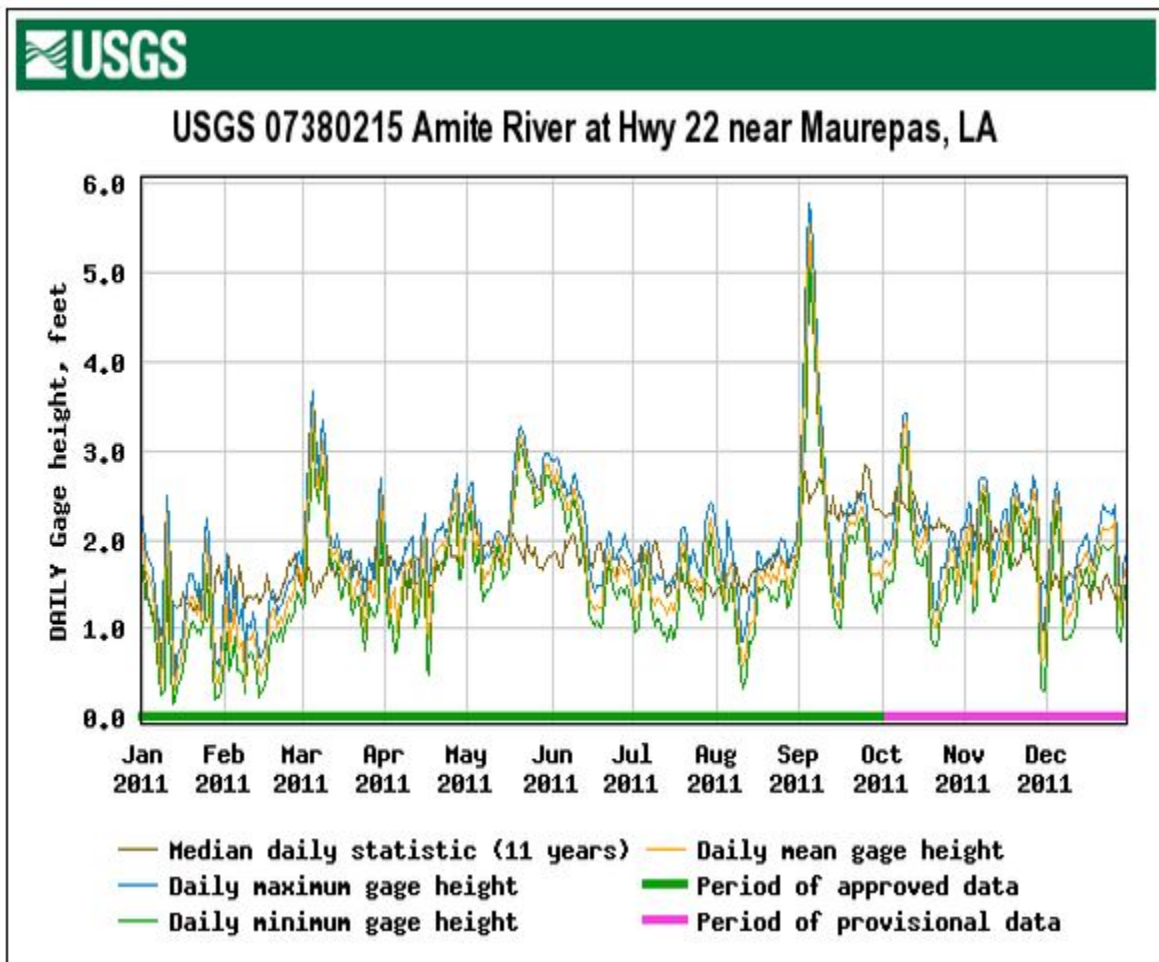


C:3 Wind Speed and Direction from the New Canal, LA NOAA station for July, 2011



C:4 Wind Speed and Direction from the New Canal, LA NOAA station for August, 2011

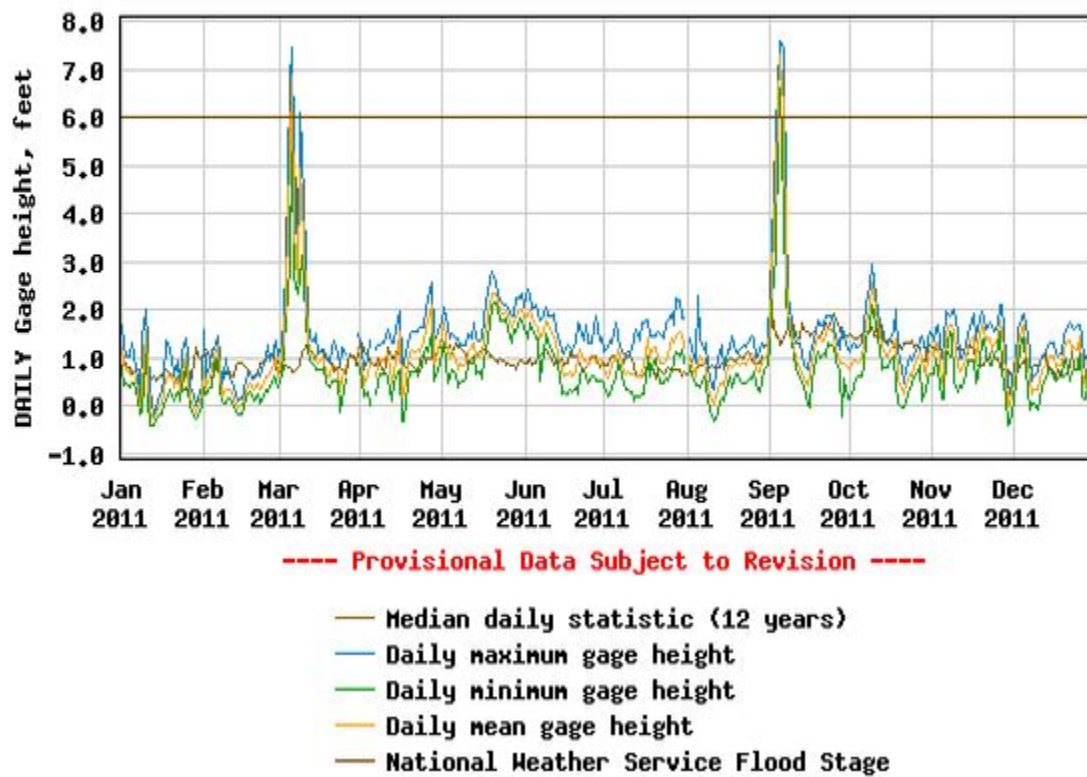
## APPENDIX C: RIVER GAUGE LEVELS



D:1 Amite River Gauge Height (ft) for 2011



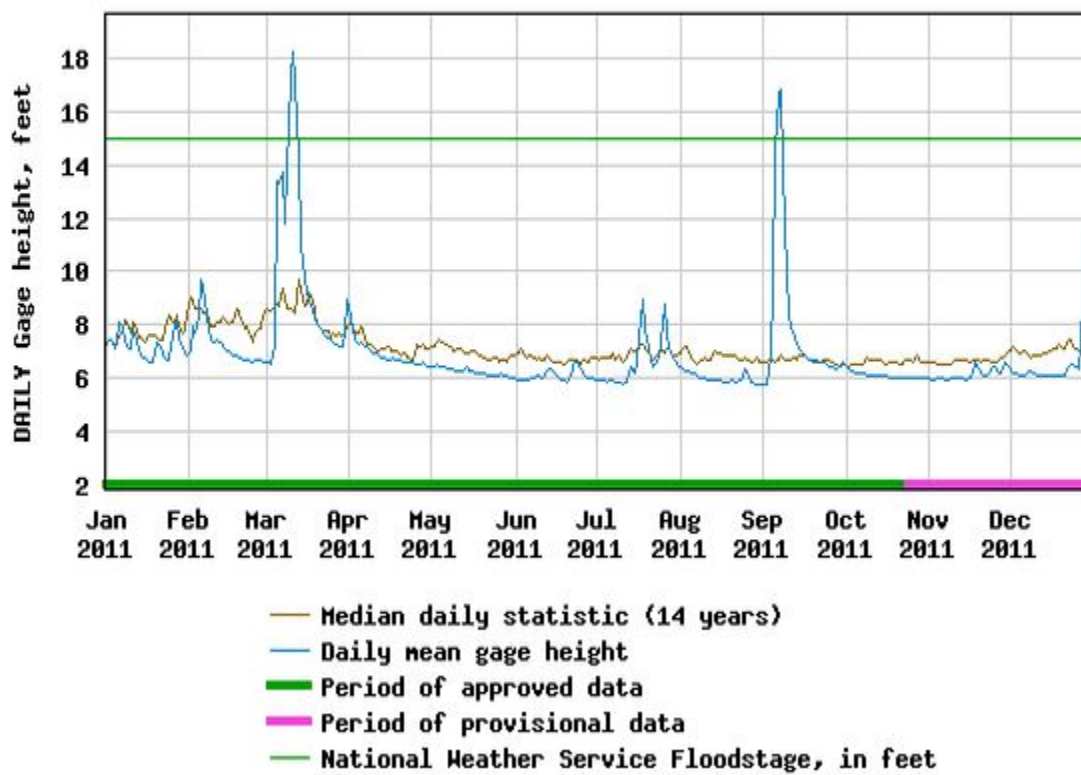
### USGS 07375175 Bogue Falaya River at Boston St. at Covington, LA



D:2 Bogue Falaya River Gauge Height (ft) for 2011



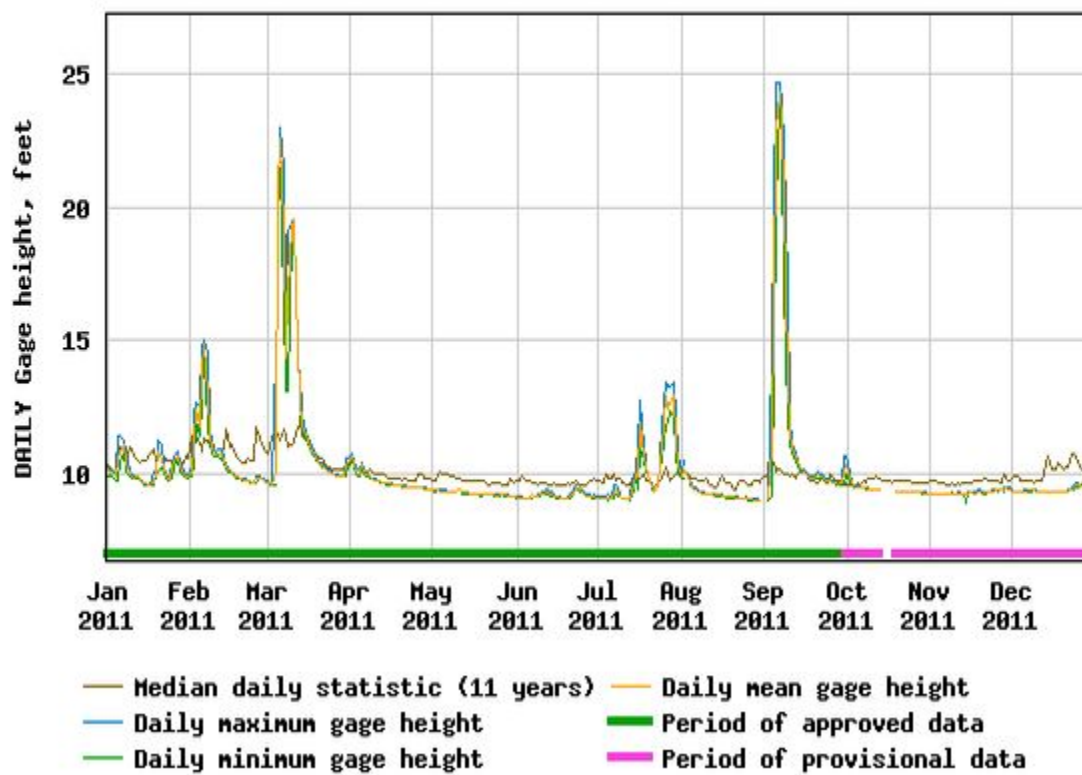
### USGS 07375500 Tangipahoa River at Robert, LA



D:3 Tangipahoa River Gauge Height (ft) for 2011



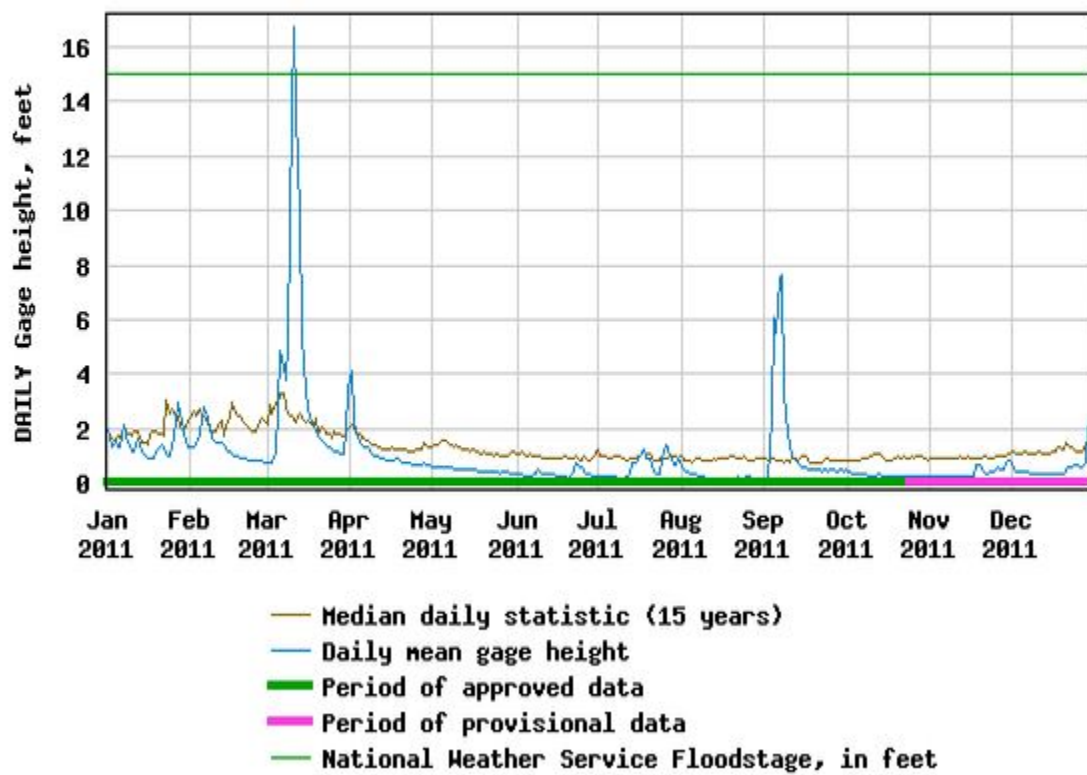
### USGS 07375050 Tchefuncte River near Covington, LA



D:4 Tchefuncte River Gauge Height (ft) for 2011



### USGS 07376000 Tickfaw River at Holden, LA



D:5 Tickfaw River Gauge Height (ft) for 2011

## APPENDIX D: GRAIN SIZE DATA

### Top 2cm Grain Size Analysis

Station #	May	July	August
05_00	22.86	9.95	25.89
05_05	8.83	13.16	9.30
05_10	7.89	6.88	7.25
05_15	7.30	34.61	8.32
05_20	19.03	13.60	17.39
07_22	11.93	23.26	18.57
10_00	n.s.	10.32	9.37
10_05	9.12	14.30	8.13
10_10	8.12	8.16	6.63
10_15	9.15	5.43	8.47
10_20	35.84	15.15	38.69
10_23	15.45	17.91	20.76
10_55	n.s.	55.99	38.32
15_00	n.s.	69.35	65.36
15_05	n.s.	14.45	32.59
15_10	7.36	8.54	9.72
15_15	34.84	6.86	10.52
20_7.5	n.s.	n.s.	24.55
20_12.5	n.s.	6.96	9.35
	μm	μm	μm

n.s. = not sampled

## APPENDIX E: FIELD SURVEY COORDINATES

### Field Survey Coordinates

Name	Latitude	Longitude
05_00	30.08	-90
05_05	30.08	-90.08
05_10	30.08	-90.17
05_15	30.08	-90.25
05_20	30.08	-90.33
07_22	30.12	-90.37
10_00	30.17	-90
10_05	30.17	-90.08
10_10	30.17	-90.17
10_15	30.17	-90.25
10_20	30.17	-90.33
10_23	30.17	-90.38
10_55	30.17	-89.92
15_00	30.25	-90
15_05	30.25	-90.08
15_10	30.25	-90.17
15_15	30.25	-90.25
20_7.5	30.33	-90.13
20_12.5	30.33	-90.21



## APPENDIX F: LAKE PONTCHARTRAIN SATELLITE IMAGERY



F:1 11 May, 2011 MODIS Image (LSU Earth Scan Laboratory)



F:2 14 May, 2011 MODIS Image (LSU Earth Scan Laboratory)



F:3 27 May, 2011 MODIS Image (LSU Earth Scan Laboratory)



F:4 1 July, 2011 MODIS Image (LSU Earth Scan Laboratory)

## VITA

Jeffrey Bryant Fabre was born in Baton Rouge, Louisiana in 1987. His parents, Brian and Connie Fabre, are originally from Terrebonne Parish in South Louisiana, but relocated to Baton Rouge after graduating from LSU. He went to Catholic High School and played basketball, baseball, and football before graduating in 2006. He would go on to attend LSU and attained a Bachelor of Science degree in geology there in August of 2011. His love for Louisiana was brought about through his exposure to the rich cultural history present in the cities, towns, bayous, and swamps his family has called home for centuries. The knowledge he gained through the study of geology and how it relates to Louisiana presented him with an outlet to channel his passion for his heritage, and he decided to enter the graduate program at LSU with hopes of studying sedimentology in the lower Mississippi River. Luckily, Dr. Sam Bentley presented him with a project that would allow him to study one of the largest diversions in the world and its implications for land building, restoration, and sustainability in the drowning landscapes present not only where his family is from, but throughout much of South Louisiana. Outside of school, he interned with Chevron in Houston during the summer of 2011 and has accepted a full-time offer with them in Midland, Texas.